# PRACTICAL RADIO

HENRY SMITH WILLIAMS

A WONDERFUL GAME FOR BOYS

Master Bob Koerner, of New York, gives his friends the benefit of records of baseball scores, or the like, from his radio-receiver. The antenna is on the roof. A lead-in wire connects with the receiving apparatus shown in the photograph. The incident typifies the activities of thousands of boys in all parts of America.

# PRACTICAL RADIO

BY

HENRY SMITH WILLIAMS

Author of *A History of Science, The Wonders of Science in Modern Life, The Story of Nineteenth Century Science, Miracles of Science, The Science of Happiness,* etc.

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To

DOROTHY WILLIAMS HARTIGAN

TENDEREST-HEARTED AND MOST WOMANLY OF WOMEN;
WHOSE VISION, POISE, FORTITUDE, AND SUPER-
JUDGMENT MAKE HER THE "RIGHT-
HAND MAN" OF MY EVERY
WORTH-WHILE ENTERPRISE

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# PRACTICAL RADIO

## CHAPTER I

### A WONDERFUL GAME FOR BOYS

IN a packet of clippings sent me the other day, I found an amusing drawing by Webster, the well-known cartoonist. The picture was one of a famous series entitled "The Thrill That Comes Once in a Lifetime," and it had appeared in the Norfolk *Ledger Dispatch*. Doubtless it was reproduced in many other papers. Certainly it deserved to be, for it symbolizes one of the most important aspects of boyhood life in America to-day.

We see a group of urchins ranging in years from perhaps six to twelve, apparently bound for school, grouped with a board fence and sidewalk and nondescript tree for background in a street of any village you may choose, between Maine and California. Two of the larger boys, standing in the center of the picture, are holding a casual conversation.

Says one:

"I tried t' git a better range by puttin' a 43-plate variable condenser in my ground circuit. Ya can increase th' wave length range on th' circuit by connectin' the condenser across th' primary."

And the other responds:

"I wrote an' ast if a loose coupler an' 2 honeycomb coils used in place of variometers would be as good as th' standard honeycomb coil set. They told me that a

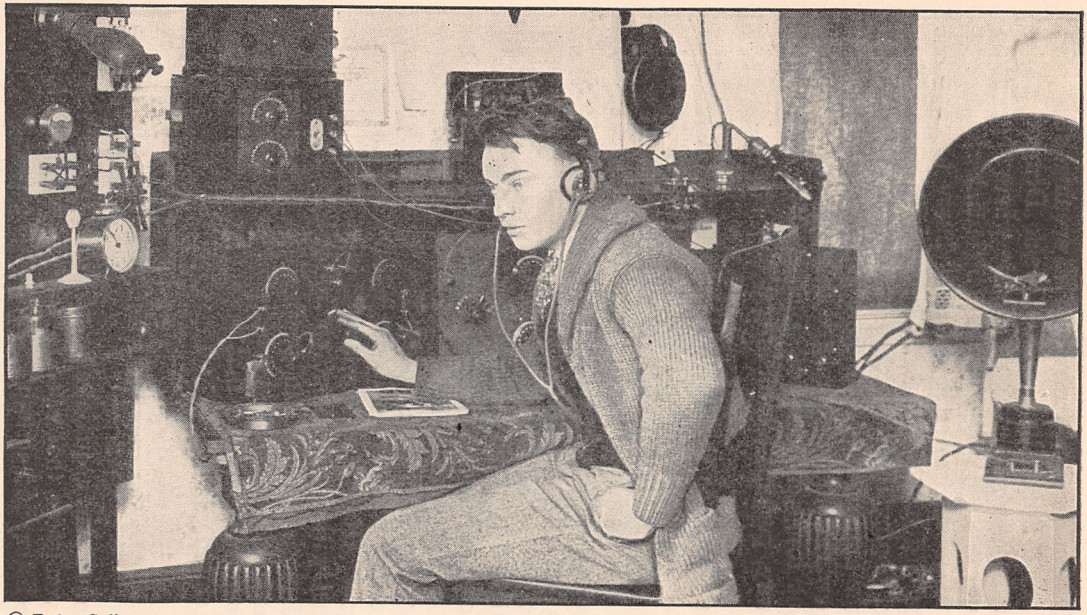
small condenser shuntin' the secondary of th' coupler an' th' grid coil would give me as good results as th' standard honeycomb coil set."

The expressive faces of the owners, no less than their words, tell what they are doing; and the blank faces of the listeners show the telling effect of the "stunts."

Like every good cartoon, this one might have been drawn from life. It is accurately symbolic of what is taking place from day to day in every village of the land. The only possible challenge of its verisimilitude might arise from the question whether, in any typical group of six boys, four could be found who would be nonplussed by the radio jargon. Certain it is that the "laymen" who serve as foils for the experts in Mr. Webster's picture will not long remain in ignorance of the subject that their companions are discussing. Even as they listen, depend upon it, they are resolving to go and do likewise; and not later than next week they too will be in position to use the radio jargon—to the mystification of many of their elders.

And let not these elders suppose that the strange words their boys—and their girls too, for that matter—are using constitute a mere juvenile jargon. On the contrary, when they talk of variable condensers, and primary circuits, and loose-couplers, and honeycomb coils, and grid condensers they are using the technical terminology of radio as a professional engineer might use it. Strange language, perhaps, to be suddenly substituted for the lingo of baseball and boxing and tennis; but a language that one must know if one would participate in the most wonderful game that any generation of youngsters ever played—the game called radio.

With what eager avidity the youngsters have taken to the game! And how marvelously they play it! Thousands of them—tens of thousands—who a year or two ago would have lingered after school to play marbles or to bat a ball about a vacant lot; or who would have



© Ewing Galloway

A BOY WHO KNOWS THE RADIO GAME

This seventeen-year-old boy, R. E. Leppert, Jr., of Harrison, N. Y., has been making radio-receiving outfits for three years. The apparatus here shown, of home construction, includes an amplifier, and has brought messages and music from radiophone stations in Chicago.

lounged about the street corners of an evening, discussing the feats of Babe Ruth and of Jack Dempsey, now hurry home and rush up to the attic where their radio outfit is installed, in order to do a little tinkering before supper time. And after supper they hurry back to the garret to "listen in" on messages that come from hither and yon, hoping that to-night they may find a way of tuning the apparatus a little more perfectly with the aid of the new variometer completed this morning, and thus reach out to listen to voices another fifty or hundred miles away, perhaps establishing a new record for their village.

To be known as the boy who has heard the farthest call is an ambition supplanting last year's ambition to be the one who could bat a ball farthest or pitch the widest curve.

In the old days, when Jack told at the supper table how he had driven a ball clear over the top of the barn off at the edge of the playground, father and mother could listen with mild amusement, the tenor of their own thoughts not greatly disturbed. But now when the boyish treble sounds from the attic with an eager "Father, come up and listen, I'm getting Pittsburgh bully to-night," it is no longer a case for supercilious indulgence. It is a case where father listens with respect and with wonderment not unmixed with humility while Jack is occupied in testing this button or that in the endeavor to get just a little better results, making explanations meanwhile that to the parental ears are quite unintelligible.

### FROM THE MOUTHS OF BABES

A professional acquaintance said to me the other day: "Do you know, that when that boy of mine gets me up there to listen, and actually delivers the goods, and when I reflect that he made the apparatus all himself, mostly

out of odds and ends, spending only a few dollars for material, I am simply flabergasted. Why, he spends every evening up there in the garret, working with his radio apparatus; and at his age I was lounging around street corners wasting my time, or worse. Think of the training that boy is getting! And all the other boys are getting the same. It is just a wonderful game to those kids. And yet they are becoming expert electricians,—trained workers in a marvelous field of applied science. The thing simply staggers me."

He reflected a few moments, pulling at his mustache, and then added:

"But I can't help thinking that a generation of boys trained like that will do something to make this a better world to live in when they get control of things ten or fifteen years from now. If we live till then, I think we shall see something."

A prophecy well worth thinking about, that. And a situation worth thinking about. The experience of that father was typical. And you need not be the father of a young radio fan to have experiences of similar import. Only yesterday I had a talk with another professional friend who has no children of his own, but who had been asked by his father-in-law, living out of town, to give him some information about radio receiving sets. My friend related that he went into a store to secure the information. As he came to the radio counter, he found two youngsters whom he described as "kids about knee high to a grasshopper," standing there in eager confab with the salesman.

"Those boys," said my friend, "were asking questions that the clerk evidently couldn't answer. He was sidestepping manfully, but they were obviously calling his bluff. I can't repeat the words they used, for they are not in my dictionary. I have a vague recollection of something about 'grid coils' and 'feed-backs' and 'honeycomb coils' and other things that meant nothing to me;

but I give you my word that those kids made me so ashamed of my ignorance that I turned about and sneaked out of the store without attempting to get the information I had come after. I'll go back again some time when there are no wise youngsters in the offing."

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A CRITICAL LISTENER

Youths like this one have become radio experts everywhere in America, and when they examine or test a piece of apparatus before purchasing, it is no mere formality. They know what they are doing.

Were those boys just "kidding," like the youngsters in Webster's cartoon? Not a bit of it. They were asking valid questions; seeking genuine information; talking about things that are just as real as balls and bats and

marbles; and the words that sounded so strange to the ears of the adult who overheard them had meanings as definite in the minds of the youngsters who used them as any words in their vocabulary. They used the big words simply because the game they are playing is so new that they had not yet found time to invent a short-cut or slang vocabulary. That will come presently.

If you doubt that these youngsters know very definitely what they are talking about, follow them to their homes, and have a look at the radio apparatuses that they have devised.

Quite as likely as not the boys there at the counter, whose questions so disconcerted the casual eavesdropper, were there to spend money they had earned in some prize contest by making a practical radio receiving phone out of a handful of junk that to you would have seemed fit only for the ash can.

There are thousands of boys who have made their own radio outfits, using odd scraps of material and purchasing nothing that costs more than a few cents with the single exception of the telephone receivers. The boy who does that certainly understands what he is doing. He knows the fundamental principles of radio telephony.

Many an adult who has purchased an expensive receiving apparatus and has learned to run it, knows very little about the mechanism of the contraption; being content to turn this knob and that in accordance with some printed directions without knowing what is happening in response to his efforts. But the boy knows what is happening. Even if he buys a receiving apparatus, he is likely to endeavor to take it apart, to find out how it works. And for the most part he does not buy it. The game of radio would not be the fascinating game it is if you merely purchased your outfit ready to use. A large part of the fun comes in making the outfit.

And the adult novice who would gain an introduction to radio cannot do better than to examine some of the

practical sets that these ingenious boys, playing the radio game with such enthusiasm, have made. There could be no better way to gain an inkling of the simple yet mystifying principles that are involved. Tradition has it that there is no royal road to learning; but here at least is an inviting entrance-gate.

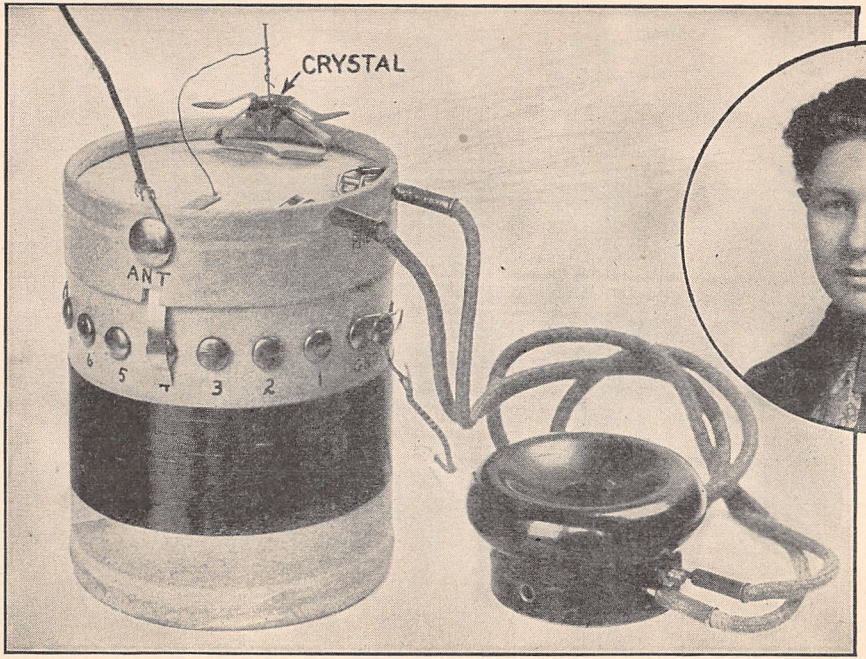
### THE SIMPLEST RADIOPHONE RECEIVER

Some of these home-made radio telephone apparatuses are simple almost beyond belief. And the simplest of all seem quite the most wonderful.

That an elaborate factory-made apparatus, resplendent with dials and full of intricate machinery, should enable you to hear voices through the air seems more or less a matter of course in these days of telephone and phonograph.

But suppose you were shown an apparatus consisting essentially of a little round pasteboard box that originally had contained a pint of ice cream brought from the soda fountain; and you observed that some one had punched some holes in the box near the top, and decorated it with a dozen or so paper fasteners of familiar type; and had wound a coil of fine wire about the center of the box, and thrust two large paper fasteners into opposite sides of the box cover and fastened a little piece of mineral in the prongs of one of the paper fasteners; and suppose that you were told that the little box had been thus oddly decorated in a half hour's time by a young man who had spent twenty-two cents on the total materials employed; and then suppose that you saw a telephone receiver attached to the box with two other paper fasteners, and were told to put the telephone receiver to your ear and listen to the radio concert coming out of the box—what then?

You would find it hard to believe your eyes and ears, would you not?




Courtesy Science & Invention, N. Y.

JAMES LEO McLAUGHLIN AND HIS PRIZE OUTFIT

It can be made in thirty minutes, he says, with a knife or razor blade and a small nail, and is "as efficient as most crystal sets now being sold." Aside from the 'phone, it costs less than forty cents. It won a prize of $100. for its simplicity and efficiency.

Yet the experience I am suggesting is one that you might have in reality had you chanced to know young James Leo McLaughlin, a New York lad who made the radio receiving apparatus just described; and who, incidentally, won a prize of $100 in gold with it in a contest held by the periodical *Science and Invention.* The editors of the periodical, in commending the apparatus as the simplest that could be made, testify that it works well. Its range of operation is only fifteen to twenty miles—but even that is a good distance to hear with an artificial ear constructed in half an hour from a pasteboard box, a handful of paper fasteners, and a little coil of wire.

It is worth our while to find out just how young Mr. McLaughlin used his materials; for when we understand his apparatus, we shall have a clear notion as to what are the essentials of a receiving set. We shall subsequently learn that there are many useful accessories in a highly developed receiving apparatus that are not essential—or at least can be dispensed with, in a short range receiver. But nothing could better prepare us to understand these intricacies than first gaining a clear knowledge of fundamental principles.

Suppose, then, we let Mr. McLaughlin tell us how he made this simplest of radio telephone receivers. A few paragraphs of interpretation will then explain just why each step was taken, and put us in position to duplicate the feat of making a workable receiving radiophone out of a handful of familiar materials.

"The important points of this set," says the young inventor, "are:

"1st. It is simple in construction and operation. A knife or razor blade and a small nail are the only tools required to make it. The complete set can easily be constructed in about one-half hour.

"2nd. It is inexpensive, the total cost, including the

phone and antenna is less than $3.00, the set itself costing only 22½ cents.

"3rd. It is as efficient as most of the crystal sets now being sold, and in most cases superior to them.

"The material required is as follows:

"1 paper container (4 in. in diameter).
13 paper fasteners (small size).
2 paper fasteners (large size).
3 paper clips.
2 oz. No. 36 enameled copper wire.
1 small piece of Silicon or galena.
1 common pin.

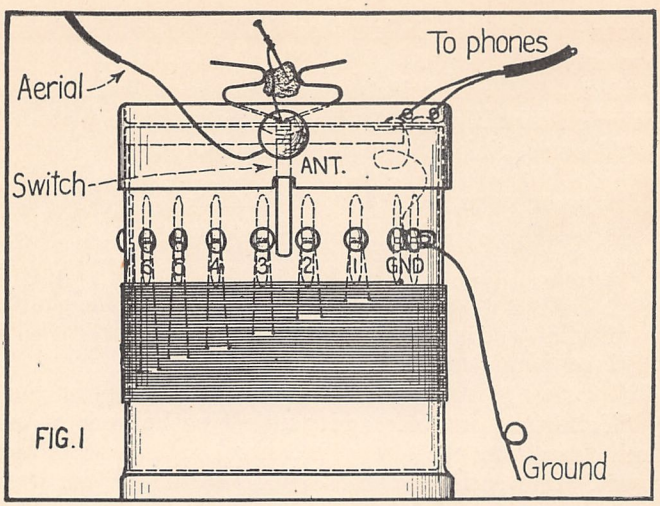
"Take the container and punch nine holes in it one inch down from the top, with a small nail, one-half inch apart. Into each hole push a paper fastener. With pen and ink number each fastener from right to left from 1 to 9. Alongside of hole No. 1 push two fasteners with a paper clip underneath—mark GND (ground). One-half inch down from GND punch a small hole; this is the starting point of the coil.

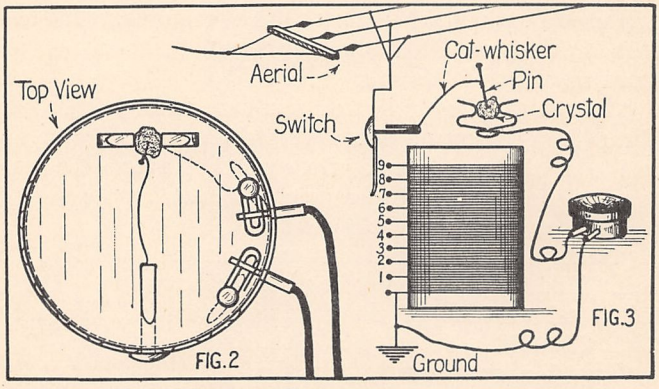
"Take the wire and push the end through the hole. Wrap the end around one of the fasteners GND (on the inside of the container). Be sure that where the wire touches the fastener, the enamel has been scraped off or else a poor connection will result.

"Next pull the wire tight and commence winding the coil. The total number of coils is seventy and a tap is taken off at each of the following turns: The 15th, 20th, 25th, 30th, 35th, 40th, 45th, and the 70th.

"Fig. 1 shows how to tap the coil. The important things to look out for are that the coil is wound as tight as possible, and that the enamel is scraped off the wire, where it makes connection with the fasteners. The 15th turn is contact No. 1, the 20th No. 2, etc."

(The young inventor is giving a description for the experts who are to examine the mechanism, so he does




Courtesy of Science & Invention, N. Y.

DIAGRAMMATIC VIEWS OF THE PRIZE SET

*Upper figure:* The tuning coil completed. Dotted lines show the interior arrangement.
*Lower figure:* Details of construction, and of final adjustment for operation.

not think it necessary to explain the utility of the maneuvers just described. For the novice, it may not be amiss to explain that the coil of wire has become what is known as a tuning coil; and that it is in effect a part of the antenna. The object of making the taps at various places along the coil is to make it possible to bring a shorter or longer portion of wire into the circuit with the antenna, in order to change the rate of oscillation of the wire, thus "tuning" it to receive messages of different wave lengths. Now comes the explanation of the simple method by which preparation is made for short-circuiting the coil at one or another of the taps.)

"The next job is the switch that moves over the contacts. Fig. 2 shows how this is made. Take one of the large fasteners, push the ends through the side of the cover, close to the lid. Bend one end down flush with the side and push the other end through the top and bend over.

"Put the cover back on the container and bend the end of the fastener so that it rides over the contacts easily, when the cover is turned, but be sure that it touches each of them. Break off the surplus end.

"The other large fastener is pushed through the lid opposite the switch and is bent, as shown in Fig. 2, so that it can hold the small crystal. A short piece of bare wire (about No. 24 will do), as the catwhisker, a pin is fastened to one end and the other end is wrapped around the end of the switch—the part that is bent over (See Fig. 2).

"Fig. 3 shows the diagram of connections and needs little comment.

"The telephone receiver is a single Murdock without head band, and can be purchased for about $2.00. Of course any other kind may be substituted.

"For the antenna one-half pound of No. 18 bare copper wire will do. This will give about 100 feet of wire. Two

porcelain cleats will also be required and should not cost over five cents. The wire can be had for about 30 cents.

"String the wire the greatest length possible, and attach outer ends to a tree or other elevation, at least thirty feet high (See Fig. 4). The other end of the wire enters the house and is attached to the switch button marked ANT and a short piece of rubber tubing should be slipped over the wire where it passes through the wall of the building.

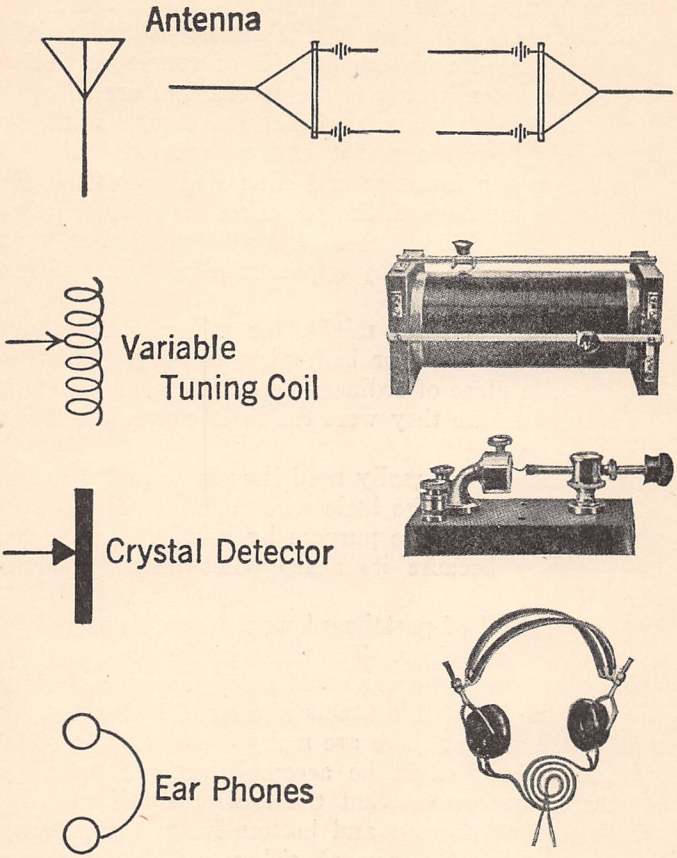
"A good ground can be had by connecting a wire to the nearest gas or water pipe. Scrape the pipe for a length of about two inches, so that it shines, then wrap several turns of the wire around it and twist tightly.

"To operate the set, bend the catwhisker wire so that the pin rests on the crystal. Move the pin over the surface until a signal is heard; at the same time move the switch over the contacts, and leave it on the one that brings in the station the loudest. With this set in New York City using only a single No. 24 wire, 25 feet long strung up in a room, WDY's and WJZ's concerts came in fine, and on several occasions, the phone could be held six inches from the ear and still the music and voice could be distinguished."

### THE SIMPLEST RADIOPHONE RECEIVER ANALYZED

It would be difficult to suggest a way in which this practical receiving radiophone could be simplified.

The fact that this apparatus received the prize among something like eight hundred competitive apparatuses, sufficiently attests its simplicity—for the prize was offered not for an elaborate or complete amateur apparatus, but for an "outfit that could be made by anyone without knowing anything whatsoever of radio or mechanics,—an outfit that could be procured readily without making special fittings, etc." Elaborate and com-




ESSENTIALS OF THE RADIO-RECEIVING APPARATUS AND THEIR SYMBOLS

The convenience of the symbols will be increasingly evident as we study hook-ups in later chapters.

plicated mechanisms, requiring exceptional mechanical skill in their construction, were absolutely barred.

But whereas superfluous parts are not to be found in this simplest of receivers, it will of course be understood that not all parts of the mechanism are of equal significance in an analysis of the fundamental principles involved. Even the novice will understand that such things as paper fasteners and clips, and even the basal part of the mechanism, the paper container itself, could be substituted. In a more elaborate mechanism, their places might be taken by apparatuses of quite different appearance.

The young inventor might, for example, have used small pieces of wire, or bent pins, or carpet tacks, or what not, in place of ordinary paper fasteners. He used the latter because they were the most convenient things at hand.

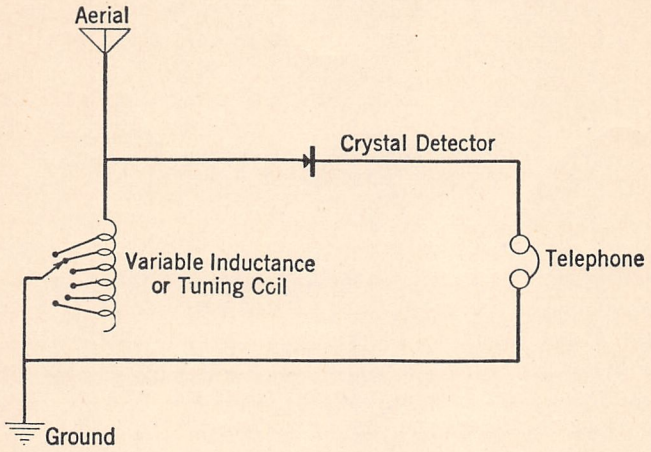
Again he did not really need the pin to make contact with the crystal. The little wire called a "catwhisker" would have served the purpose by itself. The pin was used merely because its sharp point makes a better contact.

And any roll of pasteboard would have answered instead of the container. The merit of the container was that its well-fitting cover could readily be turned about to bring the different contacts into circuit. The method was ingenious, but there are many other ways in which the same thing might be accomplished. Meantime it should be understood that the fact that the container was closed at the top and bottom has no significance whatever. A tube open at either end would answer just as well.

Turning now from these accessories to consider the really essential portions of the mechanism, we find that these are four in number: (1) the relatively long antenna wire stretched about the room; (2) the coil of wire wound about the container serving as tuning apparatus

(and in a comprehensive sense really a part of the antenna); (3) the crystal known technically as a rectifier or detector; and (4) the telephone receiver.

Of course it is essential that all of these shall be connected so that an electric current can pass through them; and there must further be a connection between the tuning coil and a water pipe, to effect what is called the "grounding" of the wire. Possibly this ground wire




DIAGRAM, OR HOOK-UP OF THE SIMPLEST RADIO-RECEIVING APPARATUS

should be named as a fifth essential part of the mechanism. But a more rigid analysis would reduce the essential parts to three; classing the antenna, the tuning coil, and the grounding wire (called ground for short) as a unit structure; and leaving the crystal detector and the telephone receiver to complete the triad. The coiled wire is so different in appearance from the strung-out aerial, however, that only the initiated would think of putting the two in the same class.

Stated in the most general terms, the function of the antenna in cooperation with a greater or less portion of

the tuning coil, is to respond to the radio waves that are coming through the air from some transmitting station miles away, developing an alternating electric current which surges back and forth; the oscillations corresponding in frequency to those of the transmitting mechanism from which the message comes. The object of "tuning" is to bring the antenna mechanism into responsive accord ("resonance" is the technical word) with the transmitting mechanism; somewhat as a piano cord may be tuned to respond to the vibrations of another piano cord.

The function of the crystal rectifier or detector is to permit half of the oscillations of the alternating current to pass, so that the current at the other side shall be a rectified or direct current. The radio waves that come to the antenna are of exceedingly rapid vibration, and so are said to be of radio-frequency. The direct pulsations that proceed to the telephone receiver from the other side of the crystal are far too rapid to be audible were it not that they are grouped or "modulated" owing to the action of sound waves made by the voice at the sending station. Each group of pulsations acts as a unit to move the telephone diaphragm.

### MAKE ONE FOR YOURSELF

All these matters will come to our attention and receive elaborate consideration in succeeding chapters. Here we are concerned only with the general consideration of the simplest principles, as supplied by an analysis of the action of the paper-box receiving radiophone apparatus.

Even should we fail as yet to understand very clearly just what is the nature of the electrical vibrations set up in the antenna, or just how the crystal effects the magic transformation from inaudible radio-frequency electromagnetic waves to sound waves of audible-fre-

DOROTHEA AND ALICE HANNA

And their radio-receiving set, which works admirably, made from a description and sketch published in the *Literary Digest*. These Indianapolis girls are thirteen and fifteen years old, respectively, and have no special knowledge of mechanics, yet they made the set without assistance.

quency—nevertheless we have gained a clear comprehension of the essential parts that go to make up a simple radio receiving apparatus.

If a score of other receiving apparatuses, each quite different in appearance from all the rest, were to be placed before us, we could analyze them and point out their essential parts. More than that, we could actually undertake with confidence to make a workable receiving radiophone outfit for ourselves, having provided ourselves with a coil of wire, a rectifying crystal, a few paper fasteners, and a telephone receiver.

EDWARD AMMAN AND HIS MINIATURE RADIO RECEIVER

This sixteen-year-old boy, of Cincinnati, Ohio, has been constructing radio apparatus for two years. This is one of his recent successes.

If we choose to be something more than mere imitators, our knowledge of principles involved enables us to branch out for ourselves, and make a receiving apparatus with an ordinary thread spool for its basal structure or one to be housed in a match box or in a safety razor case. Doubtless our first results would not match those of such adepts as young Kenneth R. Hinman, of Plainfield, New Jersey, the thirteen-year-old boy whose latest achievement is a receiving radiophone of good quality confined within the dimensions of a regular safety match box; of Edward Amman,

the sixteen-year-old Cincinnati school boy, who carries his neat little receiving apparatus in his pocket using an umbrella for aerial; or of Alfred de Giovana, fourteen-year-old freshman of the Union High School at Knoxville, Pennsylvania, whose receiving radiophone,

WIRELESS ON THE PARASOL IN PARIS

The wires serve as antenna, so the apparatus is altogether portable.

complete in every essential detail and capable of interpreting messages from fifteen miles away, is a tiny cubical box each side an inch square, and whose ambition it is to make a receiving instrument that will fit into a thimble.

But even if we failed at first (or subsequently) to match the work of these young experts, we should at least have the satisfaction of making a radio apparatus,

however crude in appearance, that would *work;* enabling us to become participants in that most fascinating of present-day games, radio receiving.

Probably the stimulus that this would give us would lead us presently to wish to pass on to other stages of proficiency at the game, utilizing more elaborate receiving mechanisms, the range of which would not be restricted to fifteen or twenty miles; and some at least of us would wish also to become out-and-out experts, acquiring the kinds of skill that would make us eligible for admission to the ranks of radio transmitters.

In speaking thus, I have in mind, of course, readers who are no longer of the "younger generation,"—but who remain young in imagination. To those who are young in years as well, it is needless to offer advice or admonition. Regardless of advice, admonition, or opposition, every boy in America will sooner or later wish to play the wonderful radio game. A host of girls will join them—have already joined, for that matter. And from the ranks of these young enthusiasts will come in due course a whole coterie of trained mechanicians and expert electricians and thoughtful students of electrical phenomena, who will open up new fields of radio practice at present unknown and scarcely dreamed of.

The prophecy that within ten years there will be a receiving radiophone in every home that now has a phonograph and in most homes that now have telephones seems not in the least hazardous. Scarcely more so is the prophecy that within fifteen or twenty years it will be almost as customary to carry a little receiving radiophone apparatus in your pocket as it now is to carry a watch. And if these prophecies, and others in kind, become realities, it will be largely because many thousands of American youths learned to play the radio game almost in childhood, and in so doing were given the opportunity to demonstrate the possession of inven-

tive talents that otherwise might never have been suspected.

For let it be recalled that this radio game, as youths are now playing it, is a man's game as well. Or rather,

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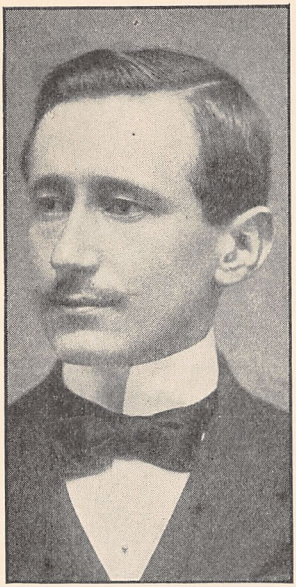
A PORTABLE RECEIVER, REQUIRING AN ANTENNA WIRE

Kenneth Hinman, of New Jersey, and his simple outfit.

considering the history of radio, one might be disposed to say that it is essentially a boy's game at which men who remain perennially young may play. It is a game that gives full opportunity for use of the imagination—for

the manifestation of inventive ingenuity; and youth is essentially the time when imagination has free play.

Only the young—including a few rare mortals who are never old—have the imagination, the courage, or if you prefer, the temerity, to attempt the impossible; to believe in miracles—and to achieve them.



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GUGLIELMO MARCONI
Taken at the time of his early triumphs, while a very young man.

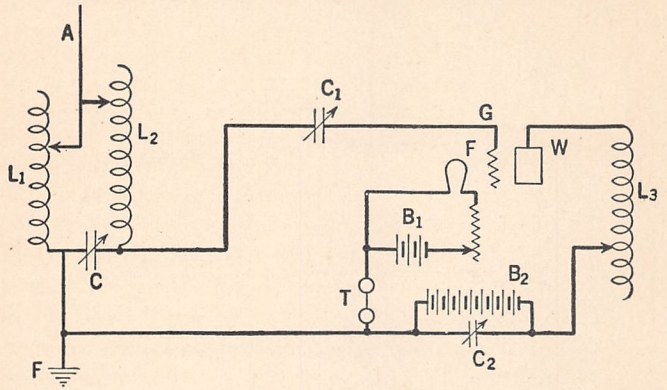
YOUTHFUL MIRACLE WORKERS

Should anyone be disposed to challenge this, let me point to the history of radio development. There we shall find our answer.

Let it be recalled that Heinrich Rudolf Hertz, called the father of radio, was but 28 when he made the demonstration of the influence of electro-magnetic waves which established the underlying principles of radio; that Guglielmo Marconi was but a boy of 20 when he began investigations that led only three years later to a convincing demonstration of the possibilities of practical radio.

Note that Lee DeForest had advanced far with his investigations before at the age of 27 he gave up a business position in order to devote his entire time to researches that culminated in the invention of the extraordinary apparatus, named by him the audion tube, which has been called the heart and soul of the modern radio receiving and transmitting mechanism.

Remember that Edwin H. Armstrong was still a school boy when he began those practical investigations with radio apparatus which led him to the discovery of a method that no less an authority than Professor Michael I. Pupin of Columbia University has named as "one of the most important inventions, if not the most important, in the wireless art," an invention which, in its

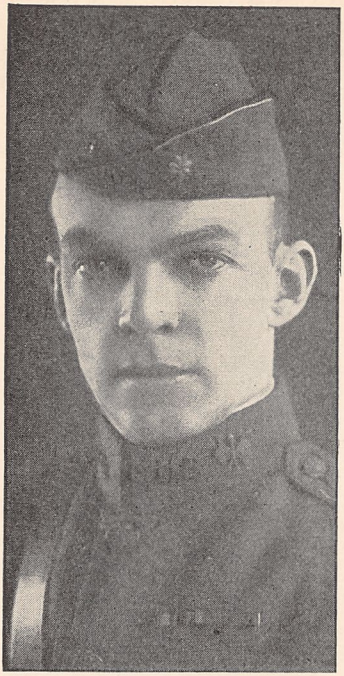



THE ORIGINAL ARMSTRONG REGENERATIVE CIRCUIT
This simple diagram, made by young Edwin H. Armstrong in 1913, was an important piece of evidence in giving validity to his patents in the long series of litigations which terminated in 1922. $L_1$, $L_2$, $L_3$, inductances; C, $C_1$, $C_2$, condensers; F, G, W, filament, grid and plate of triode detector; A and F, antenna and ground; $B_1$, filament ("A") battery; $B_2$, plate ("B") battery.

application, brought out the full possibilities of the De-Forest audion, hitherto unrealized, and was chiefly responsible for making possible the radio of to-day, with its broadcasting features and its wide-range receiving telephones.

We shall have occasion in a later chapter to follow in some detail the story of this newest development of radio; but I am minded here at the outset to depart from the historical sequence and to present certain romantic features of young Armstrong's achievement. I

do this partly because of the inherent interest of the story; partly because it is so new; but chiefly because it seems so fitting a sequel to what has gone before in this chapter; so telling a climax for the story of the most wonderful of games as played by the youth of America.

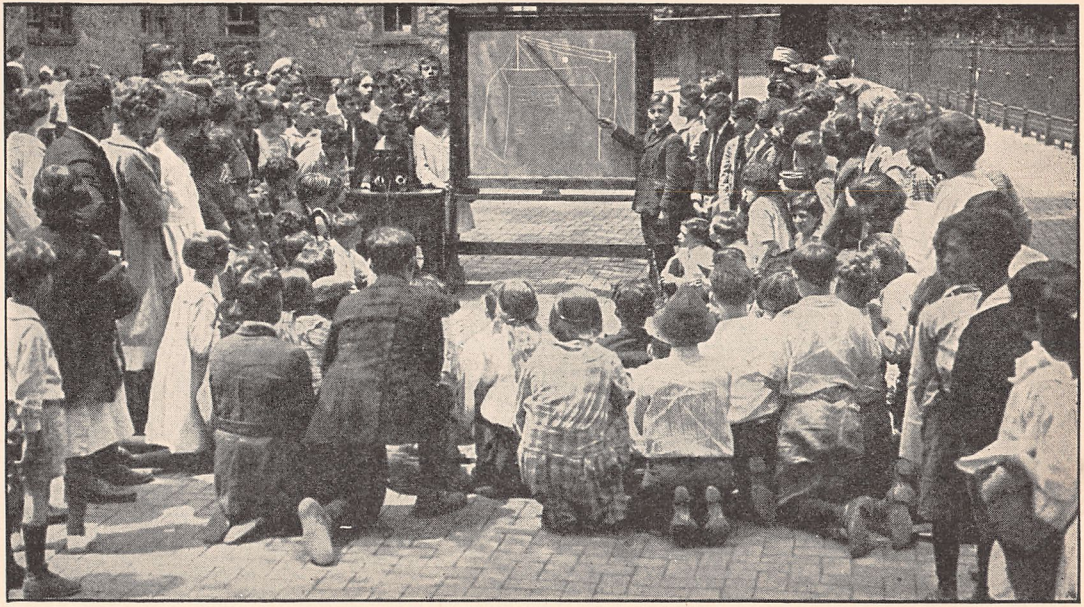


"FEED-BACK" ARMSTRONG
Major Edwin H. Armstrong, who achieved fame with the "feed-back" principle while a very young man, and who has more recently developed the super-heterodyne and the super-regenerative circuits.

### THE ACHIEVEMENT OF "FEED-BACK ARMSTRONG"

Let us, then, picture a sturdy school boy of about fifteen at the home of his parents, in Yonkers, New York, enthusiastically engaged in the year 1906, in the then very new game of radio.

The boy's interest had been aroused by reading reports of Marconi's early work. He set to work to construct an apparatus of his own. For about a year he worked unsuccessfully, but at last he began to receive messages. Then a neighbor of his, an electrical engineer, Mr. Charles I. Underhill, gave him a vacuum tube, which the doner himself did not know how to operate. Young Armstrong soon found out the secret, however, and presently he went on to experiment with the newer type of electron tube, the audion, introduced in 1907 by Dr.



A VERY YOUNG RADIO EXPERT

This eleven-year old Philadelphia lad, William Noble Allen, holds a government radio license, is an expert sender of messages, and teaches radio in a public school. He is here giving an out-of-door lecture, with school teachers and fellow pupils for audience.

Lee DeForest. The earlier tube had been of the type called the Fleming valve. It was after he had gained full mastery of the use of the audion tube, as then understood, that young Armstrong, now a college student at Columbia, was led in the course of his experiments with the current from the local plate circuit battery (the "B" battery as it is now called), to attempt to augment the incoming message-bearing current from the aerial by "feeding back" a portion of the local current into the grid circuit.

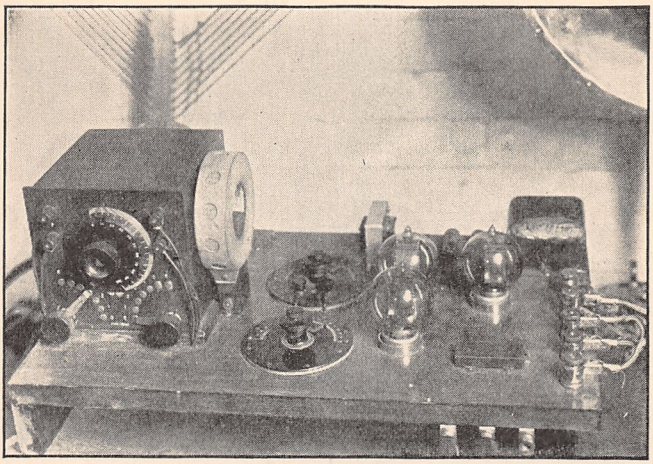
The thing worked out better than he could possibly have anticipated, and presently he was aware that he had made an important discovery.

What he had done, as the sequel showed, was to invent the apparatus afterward called a "tickler coil," establishing the now familiar "regenerative" circuit.

He could not secure financial backing to have his invention patented at the moment; but he made a diagram (what is popularly called a "hook-up") of the apparatus as he had modified it, and went before a notary in January, 1913, to have his signature on the sheet showing this diagram officially authenticated. It was a fortunate thing for him that he did this, because this simple document was the most important witness in the long series of litigations which resulted in the final verdict by the United States District Court of Appeals in which "Feed-back" Armstrong's claim to rank as the discoverer, with ownership of the important patent rights appertaining thereto, was given full and final recognition.

We shall have occasion in a later chapter to examine in detail the technical aspects of this remarkable discovery. Let it suffice here to cite the comment of Professor Michael I. Pupin, in whose laboratory at Columbia University young Armstrong worked, to the effect that the invention of the feed-back, in itself of vast importance, led the young inventor to make another most important step in wireless telegraphy, namely, the construction of

the vacuum tube oscillator. As reported in the New York *Tribune,* Professor Pupin declared that one large electrical corporation is now engaged in experimentation with powerful vacuum tube oscillators with an output of upward of 50-kilowatts. "Such tubes have practically unlimited possibilities in communication," said Professor Pupin, "while their application in other industries will



THE ARMSTRONG SUPER-REGENERATIVE RECEIVER
Details as to this new development will claim our full attention in a later chapter.

in the near future result in some revolutionary changes of vast importance."

Note, then, this further comment, as pertinent to our present theme:

" 'In this case, as in practically the case of every other important invention,' said Professor Pupin, 'it is the student who produces the original idea and not the research laboratories of the big corporations. The latter do some very wonderful and important work, especially in refinement and development of inventions, but the

conditions of efficiency under which they work hamper their originality.

"'You can't get a man like Armstrong to punch a clock. In fact I know that he was fired once for refusing to punch a clock—but I took him in at Columbia.'"

### ALMOST EVERYBODY WILL HAVE ONE

The narrator who reports the conversation goes on to say that Armstrong himself, who was present, laughed and declared that he had just "'one more thing to put over,'" and that then he meant to retire for the time being and go over to Europe for a rest. He would not say what the nature of the "one more thing" might be; but perhaps an inkling as to its character may be gained from another interview with the now famous inventor as reported in the New York *Evening Post.* In this interview, Armstrong makes the prophecy that the receiving radiophone will be as common in the not distant future as the Victrola now is.

"Not every home will have a radiophone, of course," he says, "but I can predict that every home having a phonograph will be equipped with wireless."

This equipment, it is further prophesied, will consist of none of the outside and unsightly wires, switchboards, and batteries now seen at every radio station. The whole radiophone receiver, horn and all, will be no larger than the now ordinary music box, and the current to operate it will be supplied by electric cords, connected with the nearest wall plug. Instead of the aerial wires now used, the radiophone receiver will have a small coil of wire, or a metal rod five or six feet long, something no more conspicuous than the ordinary curtain rod. Outside wires will be unnecessary.

It is further reported that Mr. Armstrong himself has this sort of equipment in his home at Yonkers even now. He has set up there a small receiver, employing no out-

side wires, which picks up music and other signals from the Westinghouse station at Newark with such strength that they may be heard for half a mile if the window is open.

A little time after the interview just recorded, Mr. Armstrong exhibited (June 7, 1922) before the Institute of Radio Engineers his newly developed receiving apparatus, to which he gives the name "super-regenerative receiver." We shall learn more about it in due course. Our present concern is with the pioneer experiment, of which the new receiver is the logical outgrowth. As long ago as 1913, the young experimenter could describe the results of his then newly discovered "feed-back" apparatus in these words, addressed to Mr. Underhill, the engineer who had supplied him with the vacuum tube:

"During the past four months I have worked up a number of improvements on the audion detector and I believe that I now have a receptor which is from two to three times as sensitive as any other, and this is a conservative estimate.

"With this receptor I can hear every navy station on the Atlantic coast from Cape Elizabeth, Maine, to Colon, Panama, including Guantanamo, Cuba, with the telephone receiver lying on the table.

"The Florida stations are so loud that they can be heard all over the room, and on good nights, Key West can be heard down on the floor below."

In writing thus, the young inventor was giving an account of results attained with a method which he has since made available for all the world. In the words of a writer in the New York *Tribune*, "no transatlantic telephone conversation can be carried on without the Armstrong principle, nor can any of the big radiophone broadcasting stations now sending music nightly through the ether operate without using the Armstrong patent. Even the modern multiplex forms of wire telegraphy and telephony must use the Armstrong method."

That is what has come from the efforts of the boy who started out to play at the radio game when his companions were chiefly concerned about ball bats and tennis racquets. When the man who has done these things chooses to enter the field of prophecy, the entire radio world must listen, and few will be disposed to question that his prediction as to a compact receiving radiophone apparatus, without aerials or other cumbersome accessories, will presently be realized. Meantime the story of his past achievements must be a perpetual stimulus to every normal youth in the land who is taking a hand in the wonderful game of radio.

## CHAPTER II

## ETHEREAL MESSENGERS

IT is more than a little startling, until one gets accustomed to it, to reflect that countless radio messages are passing right through one's body in every direction.

The thing becomes more startling, rather than less so, when you stop to think about it. You are sitting, let us say, at your desk in a New York office,—or an office in Boston, Chicago, New Orleans, Omaha, Denver, or San Francisco as it may happen. And people who to you are total strangers are talking to one another right through your body—people a hundred miles away, or a thousand, or half way round the world.

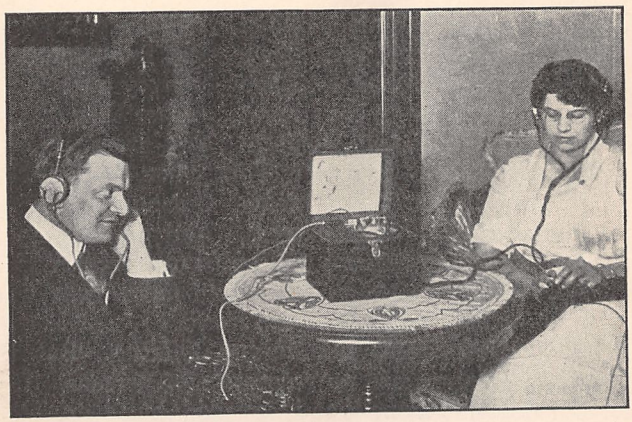
Offhand, that seems like taking liberties. But the ethereal messengers are no respecters of persons. It is not your domicile alone that is invaded, but every other domicile in the land, or for that matter in the world.

Instead of being a city dweller, you may be living a hermit life miles away from any companion, on a ranch in the far west; or you may be a farmer of the middle west, or a woodsman up in the Canadian forests. It does not matter. Wherever you are, you are very literally in the midst of radio messages that are winging their way not merely past you, but through you at a speed that would carry them nearly eight times round the world in a second.

And the strangest part of it all is that you are absolutely oblivious of the existence of these messengers. They carry their words of greeting or warning or business or love to the ears that are eagerly listening off there

to the east or west or north or south; but to you they say nothing.

It lies within your province, however, to challenge these messengers; to intercept them, to demand that they give up their message to you. And, if you go about it in the right way, your challenge will not be unregarded. In practical terms, what you must do is to provide yourself with a radio receiving outfit. We have already seen how



RADIO IN THE HOME
A simple receiving outfit.

a very simple receiving set may be made; and we shall soon learn how to construct more elaborate ones. But before we come to that, it may be worth while to reach out a little with the ears and eyes of imagination, in the attempt to gain a somewhat clear conception of the strange ethereal messengers themselves.

In so doing, the first thought that comes to us is that the radio messengers which thus go galloping about the world, coursing through our houses and our bodies without so much as saying "by your leave," belong to an utterly different world from the practical world of sub-

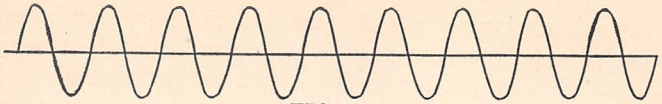


FIG. 1.

Ideal wave train, suggesting the crests and hollows of water-waves.

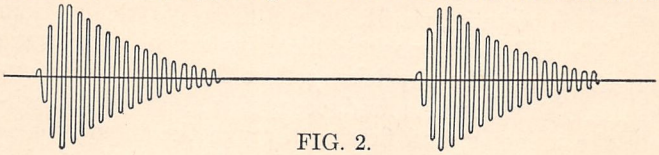


FIG. 2.

Damped waves, as sent out by spark transmitter.

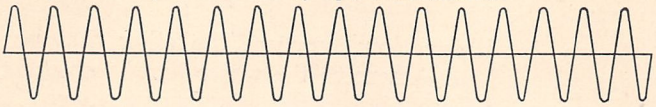


FIG. 3.

Continuous wave (C.W.), in which the waves are of a uniform amplitude.

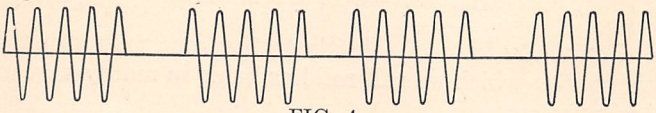


FIG. 4.

Interrupted continuous wave, the amplitude uniform, but the wave periodically broken by a mechanical device at the transmitting station.

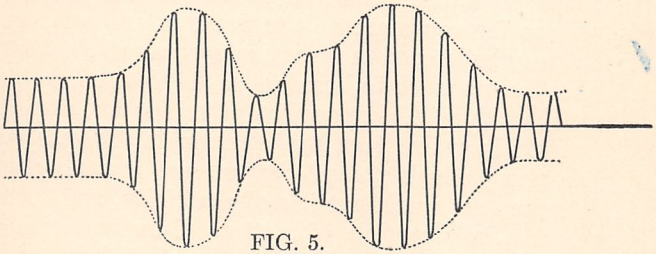


FIG. 5.

Modulated continuous wave, the amplitude being varied at the transmitting station to correspond to modulations of the human voice or musical sounds transmitted by the radiophone.

CONVENTIONAL DIAGRAM OF RADIO WAVES IN THE ETHER

stantial substances in which we live and have our being. Our physical senses give us no point of contact with them. We can neither see, nor hear, nor feel them.

The immaterial world to which these radio messengers belong is called the world of the ether. Precisely because it is an immaterial world, its real nature is hidden from us. We find it extremely difficult to conceive what the ether is like. The physicists tell us that it is a frictionless, non-compressable fluid, occupying all space throughout the universe, and flowing through the interstices of matter more freely than water flows through the meshes of a sieve.

A familiar illustration compares the ether that pervades all solid substances to the water that is absorbed by a sponge and occupies all the interspaces between its particles.

### ALL MATTER IS SPONGE-LIKE

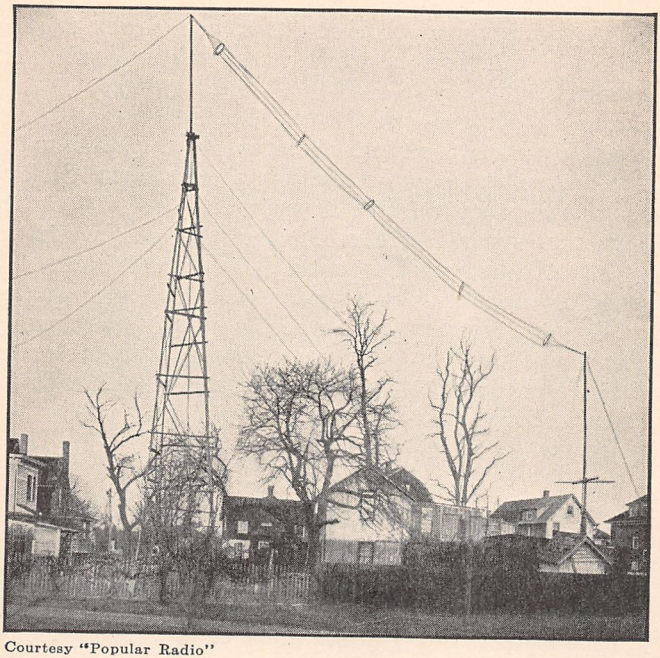
To get the force of this illustration, one must think of the matter which we call solid as being in reality exceedingly porous.

The smallest visible particles of matter are made up of myriads of molecules; and these in turn are made up of groups of atoms; and the atoms, in the ultimate analysis, so far as we are able to make it, are composed of what may be likened to planetary systems of electrons.

We shall have much to learn about the electrons before we are through with our studies of radio; but for the moment let it suffice that the electron is the smallest tangible thing which present-day science can imagine; that it represents a unit particle of electricity, and at the same time a unit particle of matter. Conceivably it is only a little whirl or flaw in the ether; but be that as it may, it is definite and tangible *something*. It has properties of mass and inertia that can be measured. It behaves in a certain definite way under given conditions.

In our present view, the thing to emphasize is that the

electron is infinitesimally small in size, even in comparison with the inconceivably minute atom of which it forms a part. A French physicist, wishing to make the matter tangible, has suggested that the electron bears somewhat



Courtesy "Popular Radio"

AN ANTENNA SYSTEM

This is of the type called "cage" antenna, because of the arrangement of the wires. A single wire usually serves for the simple amateur receiving outfit.

the same relation to the atom that a fly buzzing about in the dome of a cathedral bears to the dome itself.

If you will bear that comparison in mind, and think of the atom as being made up exclusively of a little group of electrons; and of all matter as we know it as being made up of atoms, you will get a conception of the

porosity of the substance called solid that perhaps you may not have entertained before.

Viewed thus with the eyes of imagination, the most solid substance—say a lump of iron or lead, or a granite pebble—is in reality a sponge-like structure, made up chiefly of empty space; its substance comparable to the dome of a cathedral in which a dozen or so flies are buzzing about.

Or, to use another and perhaps better illustration, each atom might be likened to a miniature solar system, with a sun and a little group of circling planets separated by some such spaces, relative to their actual sizes, as the spaces that separate the earth from the sun and from Venus and Mars and Jupiter and Saturn and Uranus.

That is probably the way the most solid substance would appear to us if we could see with ultra-microscopic vision; or if we ourselves were reduced in size to such infinitesimal proportions that the electron would serve us as a habitable planet.

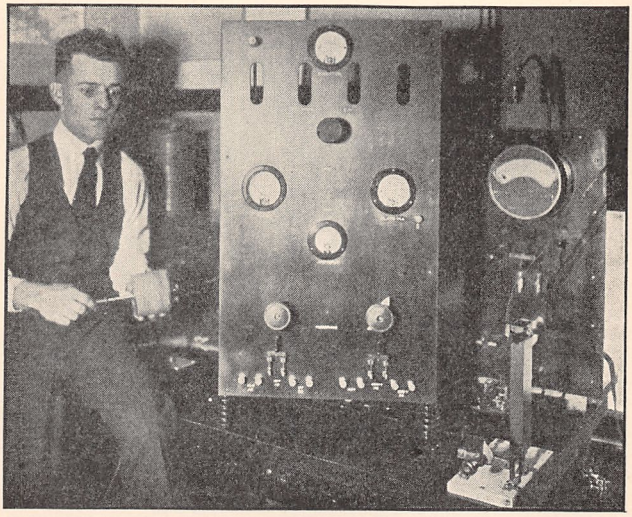
### THE OCEAN OF ETHER

I stress this illustration because it is only by gaining a clear conception of the porosity of matter that one can get anything like an adequate notion of the ocean of ether in which the radio messengers travel.

If we are to get in touch with radio, so to speak; to gain anything like a clear mental image of what takes place when a "wireless" message is sent and received, we must begin by reversing our ordinary conceptions of matter and its space relations.

We must think of the universe as an all-compassing ocean of ether in which, here and there, are minute particles—flaws if you will—which are aggregated to make up the material universe; but which, in the larger view, are scarcely more significant than a few specks of dust floating about in a sunbeam.

You would think of a room as being totally vacant even though you saw numberless dust-particles dancing about in a beam of light that came through the window. In the same way a wisely-comprehending intelligence might think of the universe as a vast stretch of empty space, filled only with ether in which at wide intervals there are specks of dust called suns and planets, and



A WELL-MADE AMATEUR RADIO OUTFIT

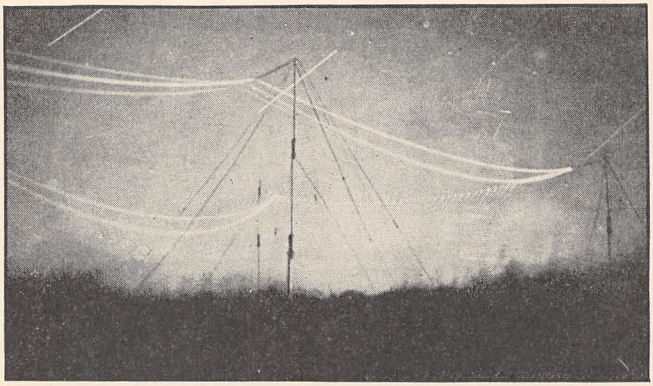
which an ultra-microscopic eye might show to be made up of even more infinitestimal particles that could be analyzed into molecules and atoms and electrons.

In attempting to conceive what this infinite ocean of ether is like, we are almost helpless because, as we have seen, there is nothing with which we can legitimately compare it. All human knowledge is a matter of comparison. In the last analysis we can think of any substance only as being like certain known substances or

unlike certain others. A thing is "as hard as a rock," or "as soft as butter," or "as yellow as gold," and so on.

And ether has neither hardness nor softness nor color, nor any other quality of substances with which we are familiar,—unless it be, perhaps, a quality that we may liken to elasticity.

Lord Kelvin, searching for an illustration, suggested that perhaps a portion of ether is more like a bowl of jelly than any other familiar thing to which we may



PHOTOGRAPH OF AN ANTENNA SYSTEM AT NIGHT

A long-exposure negative taken in the early day of Marconi's experiments in England. Nothing was visible to the unaided eye.

liken it. The jelly may be twisted about, made to quiver and wobble. The quiverings that run through it are comparable, perhaps, to the waves in the ether with which our studies of radio will bring us constantly in contact.

But there the validity of the comparison practically ends; for how can one compare a solid substance with a fluid that offers no resistance whatever to the passage of solid substances?

To the average mind the ether, so far as one can attempt to conceive it at all, will seem more like water, or better yet, like attenuated atmosphere.

When we say that it is the *something* that remains in the vacuum tube, still filling it completely after the air is exhausted, we at least have a conception of its intangibility.

But if our conception is valid, we shall reflect that the ether inside the vacuum-tube is continuous with the ether bathing all the spaces between the particles of the glass that makes up the tube. The ether is simply coterminous with space itself.

### OUR POINT OF CONTACT WITH THE ETHER

If, now, we shift our point of view a little and ask why we should concern ourselves with this ethereal *something,* which might seem rather to qualify as *nothing,*—a figment of imagination only,—we are confronted with the evidence that, even in a strictly practical sense, the ether is as absolutely essential to our existence as is matter itself. For it appears that this invisible, intangible fluid is the medium through which energy passes from one part of the universe to another.

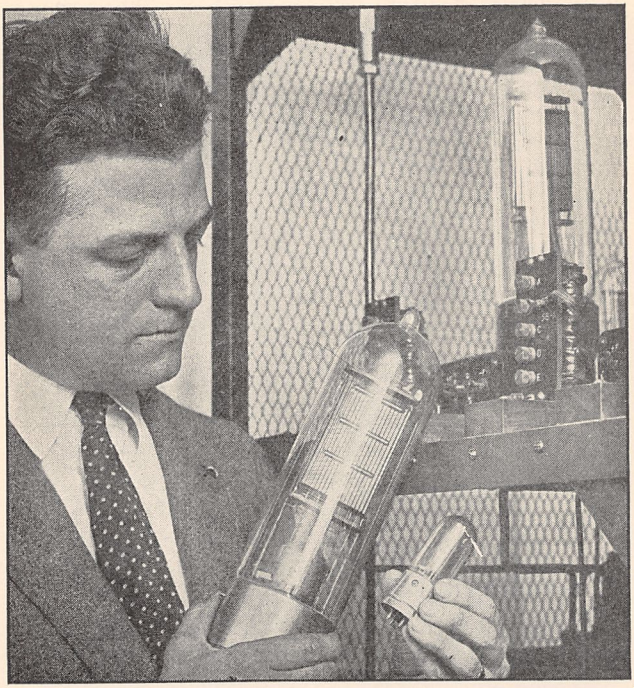
If ether were lacking, neither heat nor light would come to us from the sun; and, so far as human beings are concerned, our world might as well have no existence.

What we call light—in any and all of its manifestations—is only a series of quivers in the ether; and radiant heat, which alone keeps our world from being a solid ice-sheet, is an allied quiver, or series of waves, in the ether.

It appears, then, that our crude physical senses have their point of contact with the vast ethereal universe. Our sensory nerves make us cognizant of certain waves in the ether, as when we bask in the sun and feel its warmth; and our optic nerves make us cognizant of certain other waves, not far removed, which give us the inestimable boon of vision.

Nor is this quite all. It is familiarly known that the

groups of waves which, blended, give us what we call white light, may be split up into a so-called spectrum ranging from relatively long waves that give us the impression of red to relatively short ones that give us the



A CONTRAST IN ELECTRON TUBES, OR TRIODES

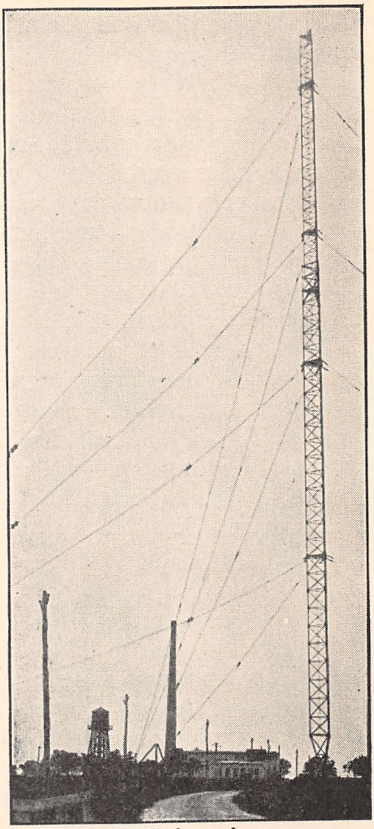
The smaller tube of ordinary size, as used in the radio-receiving apparatus. The large tube is a so-called "power tube" used at the transmitting station. Tubes similar to this are used at the broadcasting station to send out the radiophone programs.

impression of violet; and that there are still shorter waves beyond the violet end of the spectrum which to our eyes are invisible, but which make a record on the photographic plate. These ultra-violet rays have been studied

in recent years, and have been found to produce certain effects on living tissues—destroying bacteria, for example, and burning the human skin if too intensely applied—even though they are invisible.

And since Roentgen's famous discovery, we have known of yet shorter waves in the ether making up the X-rays, at which we marvel because they penetrate opaque substances somewhat as the rays of visible light penetrate glass.

Almost coincidently with the discovery of the Roentgen rays came the work of Hertz, another German, proving that, even as there are exceedingly short waves beyond the violet end of the spectrum, so there are exceedingly long ones beyond the red end of the spectrum. Not merely the waves that produce radiant heat, which had long been known; but waves of a totally different order — waves that contrast with the rays of light as the great swells of a storm-tossed ocean contrast wtih the tiny ripples running along the surface of the water.



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AN ELABORATE SYSTEM OF ANTENNÆ

A commercial radio station.

Indeed, such a comparison falls far short of the truth; for the ether waves that represent light are measured in billionths of an inch; while the Hertzian waves (radio waves as we now call them) may be thousands of feet from crest to crest.

These gigantic waves, curiously enough, resemble the infinitesimal waves of the X-ray in their capacity to penetrate opaque substances. They have, indeed, an enormously enhanced capacity for such penetration (as everyone knows nowadays, since they are the waves used in radio communication), but under ordinary conditions they do not appreciably affect the photographic film.

Their point of contact with the world we know is solely through the medium of electricity.

With the aid of an electric current the waves were generated in the original experiments of Hertz: and we still have found no other way to generate them.

With the aid of an electrified wire (antenna), the waves are interrupted and made tangible to our crude senses; and there is still no other way known to us in which these ethereal messengers can be entrapped.

### ELECTROMAGNETIC OR RADIO WAVES

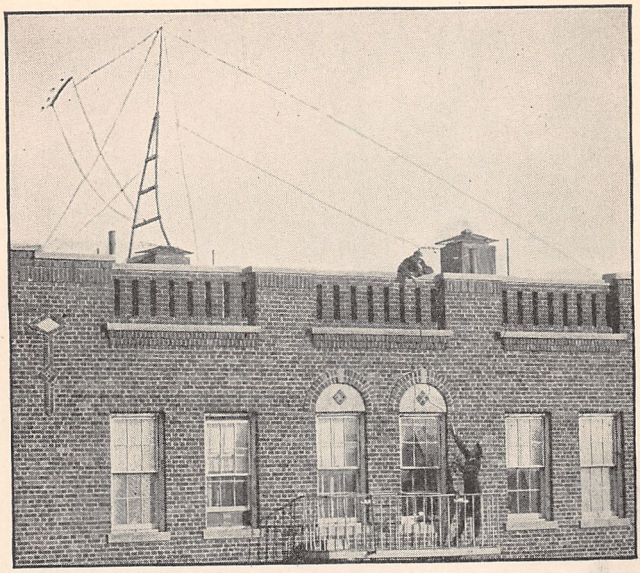
Because of their origin, these Hertzian waves have come to be known as electromagnetic waves.

There is reason to believe that they differ in no regard from the waves of visible light except in length. The comparison of the big waves of the ocean with the tiny ripples is a valid one; with, however, this added qualification: that all the waves in the ether of which we have any knowledge—Hertzian waves, radiant-heat waves, light waves, ultra-violet rays, Roentgen rays—notwithstanding their great diversity in size, move through space at a uniform rate of speed.

Thanks to astronomical observations and to curiously devised experiments in the physical laboratory, the speed

of transition has been measured, and found to approximate 186,000 miles (or 300,000,000 meters) per second.

The ethereal messengers seem mysterious at best; and assuredly not less so when we think of them as moving at



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AMATEURS INSTALLING A RADIO RECEIVING OUTFIT IN AN APARTMENT

The antenna on the roof is shown. The lead-in wire is being brought from the roof to the window of the apartment. Just how the installation is completed will be shown in other pictures.

a rate of speed that would carry them nearly eight times round the world in a second.

The fast-rolling electromagnetic waves, of the long type used in radio, like all the other ether waves with which we are familiar, tend to move in straight lines. They radiate off into space in all directions from an electrical generating source (say an antenna), just as

the rays of light radiate in all directions from a luminous source.

But it happens, very fortunately for us, that certain of the long waves are bent from their course in such a way that they follow the curve of the earth's surface,

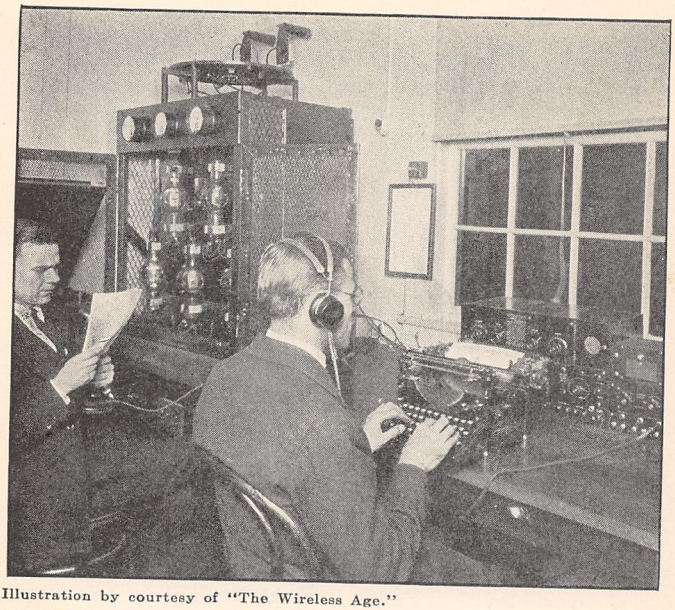
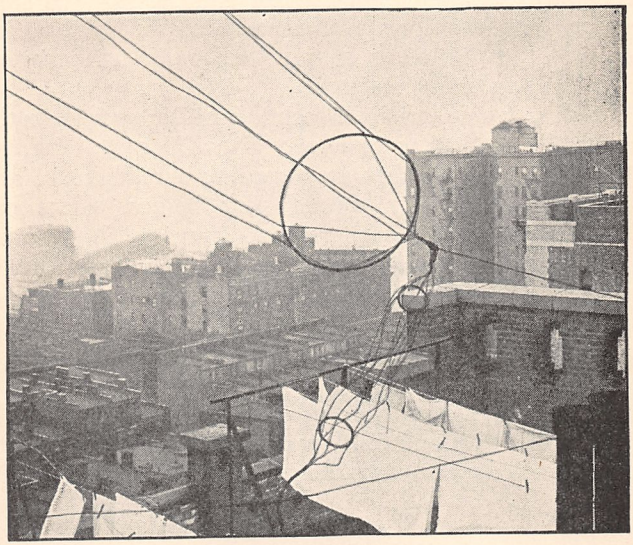


Illustration by courtesy of "The Wireless Age."

WHERE THE WJZ CONCERTS ARE SENT INTO THE AIR
The roof broadcasting stations at WJZ on Orange St., Newark, where the music from the studio is amplified and changed into electro-magnetic waves.

instead of rushing directly off into space as light-waves do; and thus they may carry their messages literally round the world. Under certain circumstances (passing near a metal structure, for example) these waves may also be bent laterally—somewhat as light waves may be deflected by reflection or refraction. As a rule, however, they go straight ahead.

It has recently been shown that the radio waves sent out from a powerful transmitting radio station are focalized at the Antipodes. Apparently waves that go east and those that go west, waves that go north and those



A CAGE ANTENNA, WITH CAGE LEAD-IN

The cage antenna, consisting merely of several wires held in cylindrical relation by a series of hoops, may be constructed with comparative ease, and is generally conceded to be efficient. Until somewhat recently it was used chiefly in military operations and amateur transmitting stations. Of late, a good many amateurs have installed this type of antenna at their receiving stations with satisfactory results. In the example shown, the lead-in wires are also arranged in a miniature cage.

that go south, finally come together at the point of the earth directly opposite the sending station, just as parallels of longitude converge at the Poles.

Whether this capacity of the radio waves to follow the earth's surface is due to an electrical or magnetic influence of the earth itself or to electrical conditions in the

upper atmosphere that have the effect of refracting the waves, is a matter that we may have occasion to discuss in another connection.

Meantime in succeeding chapters, we shall view the ethereal messengers from another standpoint. We shall inquire how the long electromagnetic waves that are generated in the ether at practical radio stations are trapped at receiving stations.

In other words, we shall seek a tangible answer to the practical question as to how you and I may take toll of the radio waves that are invading our domiciles and surging so cavalierly through our bodies. Since our normal five senses do not put us in touch with these intruding ether waves, we shall inquire what manner of mechanism may be used to give us in effect a sixth sense —call it a radio sense if you like—that will intercept them; as our eyes intercept the waves of light, and our ears the sound waves.

We shall make practical answer by building the only kind of trap for long ether waves that human ingenuity has hitherto devised—a radio receiving apparatus.

## CHAPTER III

## HEARING THE INAUDIBLE

IF you have read the preceding chapter, and allowed your imagination to expand a little, you will realize that the problem of trapping the ether waves and making them do our bidding is a really curious one.

Having learned that the electromagnetic waves are cousins-german to light-waves, our first thought might be that a radio-receiving apparatus, to entrap these waves, would be comparable to the telescope, which brings us light from stars invisible to the naked eye; or to the microscope, which shows us objects far beyond the lower limits of visibility.

A moment's reflection shows that such comparisons are not valid. The telescope and microscope at best serve only to sharpen vision. They focalize rays of light and stimulate our optic nerves to perform their normal function, merely supplying them material that would not otherwise be available.

But the radio-receiving apparatus is to deal with ethereal waves that elicit no response whatever from any of our organs of sense.

The light that the telescope brings us from the distant star is, after all, the same kind of an ether wave that comes to us as light from the sun. Our optic nerves are ready to receive it, when it is sufficiently concentrated.

But the radio waves pass directly through our bodies without producing any response of which we are conscious, regardless of whether they are attenuated or concentrated. In the immediate vicinity of the most

powerful transmitting radio station, the concentrated waves passing through our bodies produce no more sensation than the attenuated waves coming from some station a thousand miles away.

Of one and the other we are as utterly oblivious as a totally blind man is oblivious of light. There is no direct way in which these waves can make themselves known to us.

### FROM ETHER TO AIR

What is required, then, is not primarily an apparatus to concentrate the radio waves (though that might be desirable), but a mechanism that shall transform the energy of those waves into energy of a totally different type; otherwise stated, a mechanism that can interpret the ether waves in terms of some form of vibration to which one or another of your sense-organs will respond.

Offhand, one might suppose that this could best be done in terms of light—since the radio waves, like the waves of light, are merely vibrations in the ether. In practise, this can be done. The radio waves can be transformed into shorter waves that present themselves to our eyes as sparks or flashes of light. But these would serve only a general purpose as signals. We wish to interpret the waves in a much more elaborate way; and to that end, it is desirable that they should be made to appeal to our ears rather than to our eyes.

In a word, what we wish is to interpret the ether waves in terms of sound-waves.

Recalling that the ether waves may be miles in length, and are traveling 186,000 *miles* per second; whereas the sound waves are vibrations in the air, traveling only 1,040 *feet* per second, it is obvious that an extraordinary feat of legerdemain is called for. Stated in the terminology of radio, the problem is, how to transform waves of radio-frequency into waves of audio-frequency,

—meantime bridging the gap between the immaterial ocean of ether and the material ocean of air.

Only the wildest visionary, looking forward, would conceive the thing to be possible. To conceive it as possible twenty-five years ago was to brand oneself a hopeless visionary. Yet the miracle was done, as every radio

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A SIMPLE RADIO-RECEIVING OUTFIT

This is a simple crystal-detector set built by the Bureau of Standards, Washington. A full description will be given later in the present book. From left to right, the switchboard, the tuning coil, the variable condenser, and the holder for the crystal detector.

amateur who puts telephone to ear and receives a "wireless" message can cogently testify.

The practical mechanism that makes the miracle possible is called a radio receiving apparatus. Let us now make further inquiry as to what are the essential parts of that apparatus, and as to how they operate.

The bald essentials of the apparatus (as we learned in an earlier chapter) are: (1) a conductive wire, which will intercept the radio waves and transform their energy into electrical energy; (2) a tuning apparatus to bring the mechanism into harmony with the distant transmitting radio mechanism; (3) a so-called "detector," the province of which is to permit the electric current to pass in one direction only, thus sifting out and eliminating the reverse current of the alternating series and producing a pulsating current; and (4) a pair of telephone receivers of high resistancy, the diaphragms of which will pulsate at "audio-frequency" and produce the sound waves that your ear-drums will receive and the auditory centers of your brain interpret.

Let us briefly consider the essential characteristics of each of the successive members of this receiving apparatus. It is true that we have already (in Chapter I) examined such an apparatus, of very primitive type; but only in a cursory way. Now we must take up the details of construction of a somewhat less primitive, though still simple, radio-receiver. In subsequent chapters we shall have occasion to examine still more elaborate mechanisms and the theory of their action. Here it will be best to deal with essentials only, in effect answering the question:

How may we install a simple receiving radio-telephone apparatus that will enable us to hear the programs of a broadcasting station perhaps twenty or twenty-five miles distant?

We are to make, then, an apparatus somewhat more substantial and somewhat more sensitive than the one described in Chapter I; yet an apparatus at once inexpensive and easy of construction.

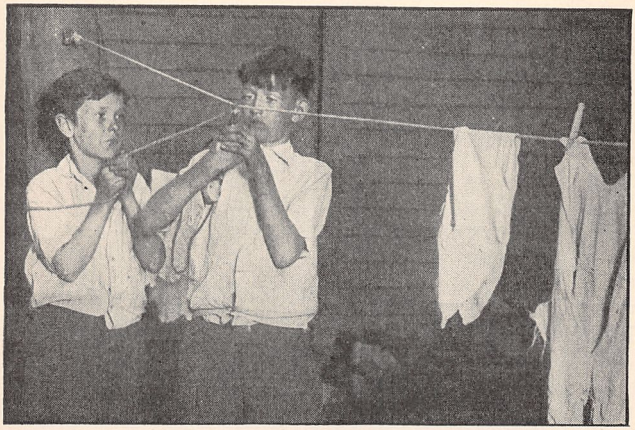
### THE RECEIVING ANTENNA

Our first concern is with the installation of the wire along which is to be generated the electric field that alone

(so far as experience goes) can interpret the radio waves.

In his pioneer experiments, Hertz used a loop of wire, which he likened to the sensitive feelers of a moth or butterfly, and hence called an antenna. And this name has been universally adopted.

The name has peculiar propriety if we accept the opinion of some physiologists that the antenna of the



A CLOTHES LINE AERIAL

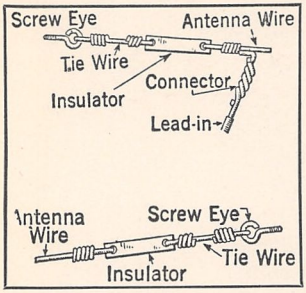
It has been found that a wire clothes line will serve on occasion as a receiving antenna. The boys in the picture are utilizing this knowledge. They are adjusting a lead-in wire which will make the clothes line an "inverted L" antenna. There must be an insulator at either end of the wire clothes line.

moth is virtually a sixth organ of special sense, enabling the insect to perceive vibrations in the air—or perhaps in the ether itself—that are not appreciated by any other organ. In any event, the antenna wire of the radio outfit is a sensitive feeler that establishes contact with electromagnetic (radio) waves, the very existence of which we could prove in no other way.

The most conspicuous part of the antenna, being

usually placed at an elevation out of doors, is commonly referred to as an "aerial."

The first thing to know about this all-important antenna, or aerial, is that it might be made in a pinch, of almost any fragment of metal that will conduct electricity, and can be insulated. The insulation here referred to, it should be explained, is not the coating of the wire with a non-conductor, as an ordinary electric-light wire is coated. Whether or not the antenna wire is thus insulated, does not matter. The radio waves pay no heed to a mere coating of rubber and braided cotton surrounding a wire. The insulation of the antenna now in question means merely that at its terminus there must be a connection that will prevent the electric current generated by the radio waves in the wire from escaping that way. Details as to this will be given presently.




ADJUSTING THE ANTENNA WIRE

These diagrams are self-explanatory, showing methods of adjusting the antenna wire, with particular reference to the installation of an insulator.

To repeat, the antenna, or aerial, may be made of any isolated strip or network of metal. A bed spring has been made to answer, or the frame of the bed itself. A young amateur of whom I know uses strips of tinfoil fastened along one side of a silk curtain, hanging against the wall of the room in which he operates. A fire escape has been made to serve; also the call-bell wire in the wall. In the country, a strand of a wire fence has been pressed into service.

In a word, any metal apparatus that will conduct electricity and can be isolated (electrically) may be used as a trap for the radio waves.

But of course this is not to say that there is no choice

as to strips of metals. As a matter of course, there is a choice. A strand of phosphor bronze wire makes the ideal antenna; and fortunately this is not difficult to secure. Nor, in the quantity required, is it unduly expensive. Pure copper wire; steel wire with copper coating; and stranded copper wire are also used on occasion.

The size of wire to be selected will depend somewhat upon the length of the aerial; and that, in turn, is to a considerable extent a matter of convenience or expediency. But the length of the antenna, it must be understood, predetermines to a considerable extent the receptiveness of the receiving apparatus. With an aerial thirty to fifty feet long, you may catch short waves from nearby stations; but if you are to reach out for longer waves, as you probably wish to do,—and as you are sure to wish to do sooner or later,—you should have a wire the aerial portion of which is at least one hundred feet in length. If your home is in the country, where space is no consideration, you may make it twice that, or more.

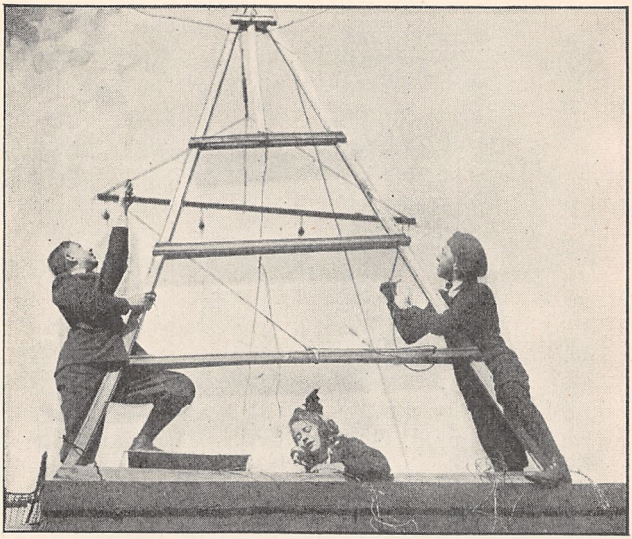
When Mr. Paul F. Godley went to Scotland to prove that amateur messages from America could be heard across the ocean, he erected a line of 1300 foot stretch—about twice the wave length of the expected messages. Incidentally, it may be noted that his line was pointed "directly toward Chicago," so that the electromagnetic waves to be received would wash along the whole length of the line, thus encountering a maximum resistance and developing a maximum current. That, of course, was because he was anxious to receive the messages from a single direction with maximum intensity. The same line, however, would collect messages from every other direction, though not with quite the same degree of efficiency.

### INSTALLING THE AERIAL

Assuming that your aerial is to be of ordinary type, and about a hundred feet in length, No. 14 wire will be found best suited for your purpose. A single strand of

wire stretched in one direction (without turns) will answer best for a receiving antenna, which of course is what we now have in mind.

If some time you become a radio expert, and attain



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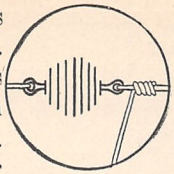
YOUNG AMATEURS PUTTING UP AN ANTENNA

It will be seen that one of the boys is "listening in," to test the antenna. One may suspect that the picture was posed for the occasion, but there is no reason why the wire should not be tested while in process of adjustment.

eligibility to the ranks of senders of messages, you will need a more elaborate aerial, comprising several strands of wire in parallel at intervals of two or three feet, all the wires being electrically connected. A so-called "spreader" for holding the wires at proper distance may be purchased, or its equivalent may be constructed by the amateur without great difficulty. A bamboo pole furnishes excellent material.



But this is looking ahead. The novice has no concern with sending messages. He is to be for the present a listener only; and the simple type of aerial will best serve his purpose.

The aerial part of the antenna, as just described, whether of single wire or of several, is usually stretched at a considerable elevation. In the city, the roof of an apartment house often gives excellent opportunity for a proper adjustment of the more or less horizontal wire or set of wires. There is no need to have the wire precisely horizontal. It may slope at any angle.

As a rule, no attention can be paid to the direction in which the wire points. It is well to recall, however, that maximum intensity of reception will be secured with waves moving parallel to the direction in which the aerial wire is stretched.

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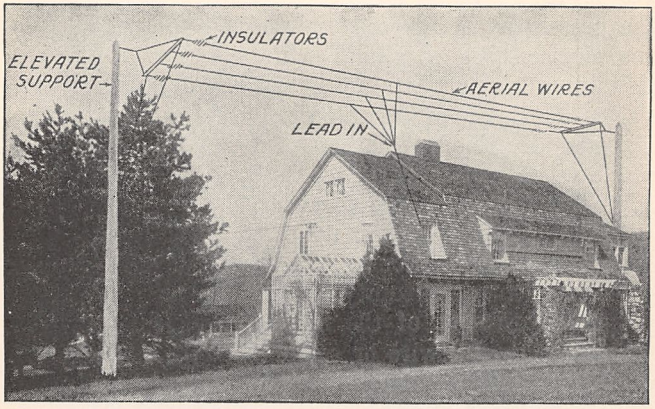
REPAIRING THE ANTENNA

The inset shows details of lead-in wire neatly twisted about the antenna wire near the insulator.

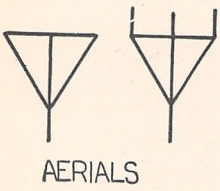
If there is some particular broadcasting station to which you especially wish to listen, you will do well to arrange your antenna, if possible, pointing in that direction. But in any event you will receive messages from every direction, and the difference in range with your comparatively short an-

tenna may not be so very markedly appreciable between one direction and another.

If, however, you are putting up a very long antenna—say five hundred feet or more—there is very marked advantage in having it point in the direction from which




From "Popular Radio"




A SOMEWHAT ELABORATE "T" ANTENNA

It will be seen that there are four wires here in parallel, properly spread, and with four corresponding lead-in wires converging to a single wire. For purposes of the ordinary amateur's receiving set, a single antenna wire usually suffices.

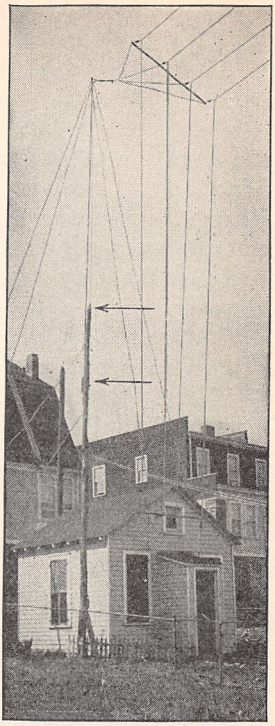
you hope to receive most distant messages. But there are reasons, to be detailed later, why it is not desirable for the novice to use an unduly long aerial. Questions of "tuning" are involved, as we shall see.

The two conventional types of aerials in most general vogue are known as the "T" and the "inverted L" types. The former is so called because the "lead-in" wire connecting with the receiving apparatus and with the ground descend from the center of the horizontal line or lines.

The other type has a bend or knee like the corner of the letter L,—the upper part of the letter, however, being represented by the horizontal portion of the antenna. The bend (constituting the lead-in wire) in the case of the inverted L aerial should be at the end toward the transmitting station.

As a matter of course, it is important that the ends of the aerial should be securely anchored,—so that they will not blow down in the first storm. On the roof of the city dweller, chimneys or the legs of water tanks may serve as anchors. In the country the aerial may be stretched between house and barn; or a tree may give anchorage at one or both ends.

The height at which the aerial is stretched is not now considered as important as it formerly was. Quite recently important tests have been made by various experimenters, notably by Professor Taylor, of the University of North Dakota, in which the antenna was stretched along the ground. The objection to this, however, is that in the hands of the ordinary amateur it is difficult to secure proper insulation. Moreover the surrounding topography must be considered. Hills and trees tend to obstruct the radio waves, and large buildings to some extent interfere with them.



A FOUR-STRAND ANTENNA OF "INVERTED L" TYPE

The arrows indicate the adjustment of the metal rod or pipe above to the wooden pole that constitutes the lower part of the upright. This antenna is more elaborate than the ordinary amateur requires.

In most cases, the aerial stretched at some distance from the ground will be preferred in any event, because it is out of the way, if for no other reason. It may be desirable to stretch the wire at a considerable height—as in cases where a chimney on the house and a cupola on the barn afford anchorage. But it may be noted that Mr. Godley's receiving line over there in Scotland, which brought him messages from more than a score of American amateurs, across the Atlantic, was stretched on posts (2 x 4 inch) only twelve feet high,—in open country, however.

Whatever the height or direction or manner of anchorage of the aerial, the question of insulation at its ends is all-important. If expense is not a consideration, the electric insulators to be purchased at any supply store are, of course, admirable and convenient. But a great many amateurs resort to makeshifts in insulating the aerial, as in the construction of the wire system itself.

As Mr. H. W. Secor has said, in cruising about the country, you not infrequently "bunk into one of the greatest freaks of modern times, a real dyed-in-the-wool amateur antenna—constructed from about six kinds of wire including some good old iron hay-baling wire, and a variety of insulators that would win first prize in any freak photo-contest, made from miscellaneous odds and ends, including near-beer bottles, porcelain cleats, wax wooden rods, pieces of crockery, and other choice bits of 'back yard junk.' "

And these freak antennæ frequently serve their purpose admirably. The essential point is that there must be sufficient conducting metal to be electrified, and that insulation is adequate to prevent the current from leaking away to the ground.

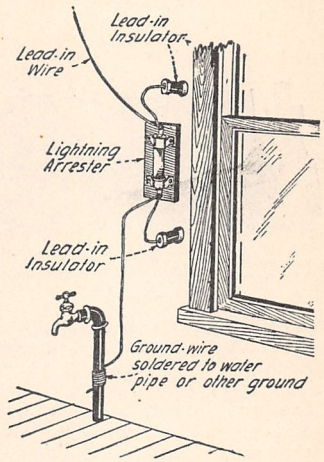
### GROUNDING THE ANTENNA

Meantime it must not be overlooked that the antenna system as a whole is incomplete until the aerial is con-

nected with the ground through the proper channel,—which includes the receiving apparatus itself.

The ground wire must be led to earth, either directly or through the medium of a water pipe. With a city dweller, of course, the water pipe is universally selected as being both convenient and efficient of operation. The pipe should be scraped clean; good contact made with the twisted wire, or with a clamp; and the juncture soldered.

In the country, the wire must be carried to earth and buried to a depth that insures invariable moisture. If a moist soil is not available, the ground may be moistened artificially from time to time. Sometimes the ground wire is carried into a neighboring pond or river. Dry soil acts as an insulator and will not serve the purpose—which is to act as "counterpoise" to the aerial, permitting the current of electricity to surge back and forth.



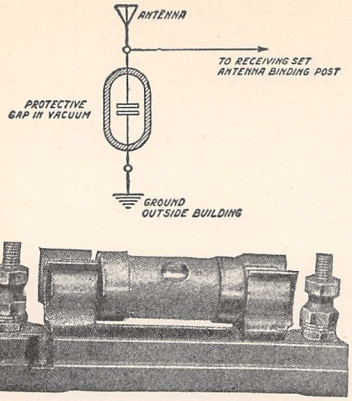

DETAILS OF ADJUSTMENT OF LEAD-IN WIRE FROM ANTENNA

The adjustment, including the lightning arrestor, and the ground connection, may be on the inside of the house, as is customary in city apartments; or on the outside, as is usual in the country.

Aerial and earth constitute, in effect, plates of an electrical condenser, with the intervening air as "dialectric," as will be more fully explained, when we take up the theory of radio action more extensively.

### PROTECTION AGAINST LIGHTNING

In addition to the station ground just referred to, which serves an essential purpose in connection with the work-




PROTECTION FROM LIGHTNING

A vacuum-gap lightning arrestor, the manner of construction of which is shown in the schematic diagram. The small vacuum space between the ends of the wires of antenna and ground, respectively, prevents the passage of the ordinary input radio current; but should an excessive charge of atmospheric electricity accumulate on the wire, it will escape to the ground across the vacuum gap.

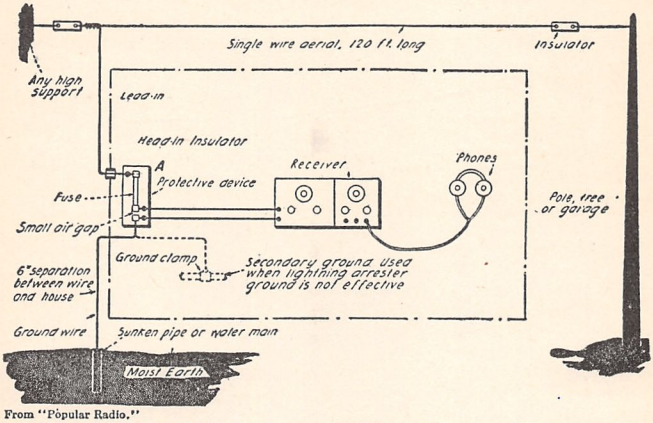
aerial itself should be of No. 4 gage solid copper conductor or its equivalent in cross-sectional area. If the aerial has more than one wire, the lead-in for grounding must come from each strand, the various wires being bunched at a convenient point, and all joints should be soldered.

The lightning ground ing of the radio receiver, it is necessary to have a grounded wire for protection against lightning. The Fire Underwriters' older rules covering the grounding of radio antennæ called for a ground wire connected to a first class ground plate or pipe running down to damp earth, or to the street side of water mains in cities, this ground wire being composed of No. 4 B & S gage solid copper conductor. The ground wire connects to a grounding switch rated at 600 volts and 100 amperes. It was recommended that the lead-in wire from the

LIGHTNING SWITCH

This single-throw lightning switch, operated like a lever, to connect the antenna directly with an outside "ground," has to a considerable extent been superseded recently by the vacuum-gap lightning arrestor. Both apparatuses may, however, be used in connection with the same receiver.

and switch must, according to the older ruling, be placed on the outside of the building in all cases. The switch may be on the window sill, or at the side of the window, covered with a box to protect it from rain and snow. The ground wire running down the side of the building need not be insulated. Bare




From "Popular Radio."

DETAILS OF WIRING OF ANTENNA SYSTEM WITH PARTICULAR REFERENCE TO LIGHTNING PROTECTION

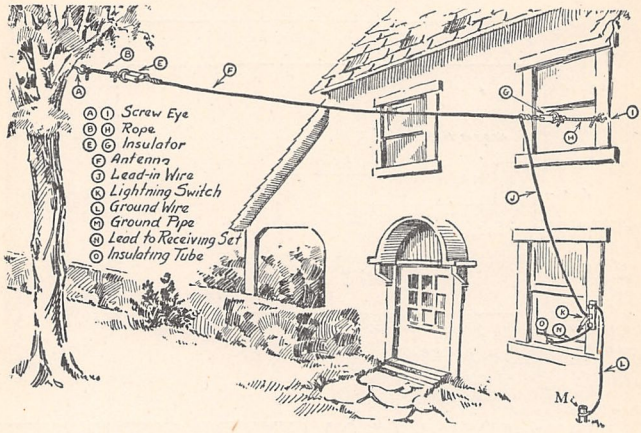
It will be seen that the antenna lead and the ground lead of the receiver pass to the vacuum-gap protector. The connection may be permanent, without danger to the receiver from atmospheric electricity, which, if excessive, would jump across the gap in the protector. A properly grounded antenna serves as protection against lightning.

copper wire is usually employed. It is very important that the wire should run in as direct line as possible, as lightning does not like to turn corners and is likely to jump from the wire with destructive effect if called on to make a turn.

It is imperative, also, that the wire should be led to moist earth, however deeply it must be carried, or to a water-main.

The object of the lightning ground is, of course, to

convey to the earth, and thus to carry off, electricity that might otherwise accumulate on the aerial wires, particularly during thunderstorms. To provide a wire that terminates in dry ground and is thus insulated at the end, merely gives opportunity for a greater accumulation of electricity, and thus invites disaster,—for, when the




AN "INVERTED L" ANTENNA ADJUSTED BETWEEN A TREE AND THE WINDOW FRAME

The details of adjustment are well shown in the drawing, including the lightning switch, which may be swung downward to convey the radio current to the receiver, or upward to make connection with the outside ground wire, when the receiver is not in use, or when a thunder storm approaches.

charge is sufficient, it will (theoretically at least) break away from the wire at some convenient point, providing a lightning stroke instead of protection.

It should be explained, however, that there does not appear to be any record (at least none has come to my attention) of an actual lightning discharge using a radio antenna for its channel. There has been much talk about the subject, but most of this is apparently founded in vague fears that have no warrant. A well-installed

antenna should serve as a lighting rod, giving protection. Even a poorly grounded aerial, as has been pointed out by a recent writer, is much less of a menace to a house than such familiar things as metal roofs, metal eaves, troughs and water spouts, and wire clothes lines, to which no one appears to have paid any attention.

That atmospheric electricity may find the aerial a conducting channel, is obvious enough, and demonstrated by the phenomena of "static." But the very fact that electricity is thus conducted to the ground, in itself suggests the protective influence of the aerial.

The Board of Fire Underwriters have recognized, apparently, that their earlier rulings were guided by solicitude rather than by scientific knowledge, and they have recognized new rulings, suggested by radio authorities, including the Bureau of Standards experts, according to which it is not necessary for the city dweller to use an outside ground. A so-called lightning arrester, preferably in the form of a vacuum-gap apparatus, is required, taking the place of the lightning-switch; although the latter may be shunted across the arrester as an additional safeguard.

In any event, the danger from a small wire aerial adjusted on a steel-frame building must be negligible. The entire frame work of the building, and most of the metal pipes, are grounded, and serve to constitute a highway for atmospheric electromagnetic charges that insures safety against the accumulated charge that reveals itself as lightning.

To put an ordinary lightning rod on one of these buildings would be ridiculous. It is equally ridiculous to suggest that the installation of a tiny radio antenna there will endanger the building.

### PRACTICAL DETAILS OF ANTENNA CONSTRUCTION

The description just presented gives a fairly comprehensive view of the principles involved in the construc-

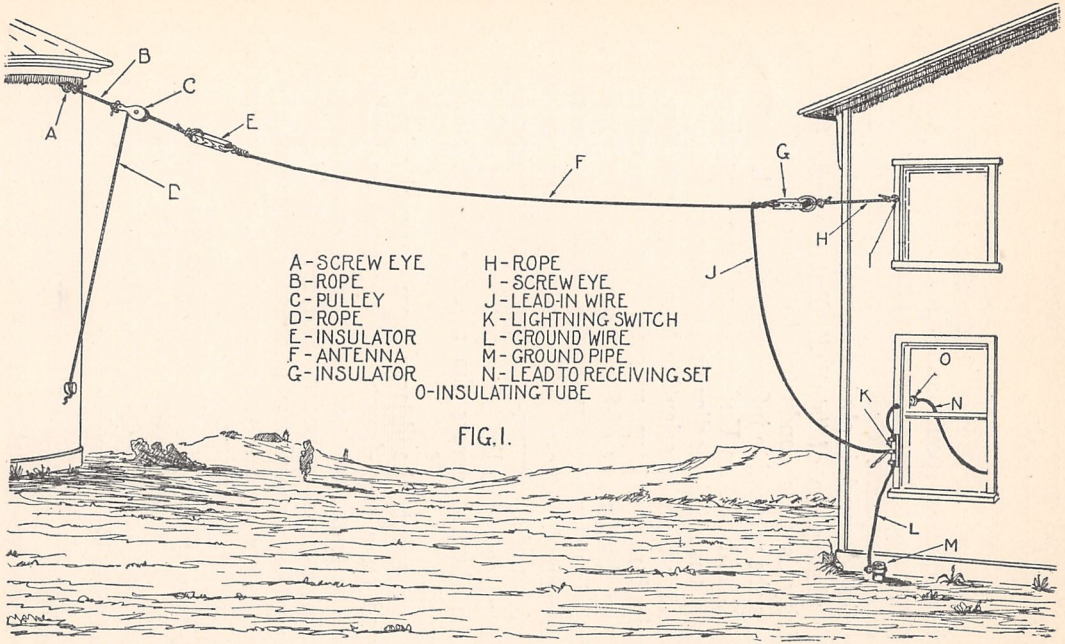



FIG. I.

AN "INVERTED L" ANTENNA ADJUSTED BETWEEN TWO BUILDINGS

It will be seen that there is a pulley adjustment that permits lowering of the horizontal wire; or the tightening of it if it slides and sways in the wind.

tion of the antenna for our proposed receiving outfit. It may be well, however, to supplement this with more elaborate directions as to certain practical details. To that end, the instructions given in a bulletin issued by the Bureau of Standards of the Department of Commerce may advantageously be cited. If the account involves a certain amount of repetition, that will serve to emphasize what has already been said. Here, then, are brief, practical instructions for the installation of a simple antenna, with lightning switch and ground connections.

The antenna is simply a wire suspended between two elevated points. Wherever there are two buildings, or a house and tree, or two trees with one of them very close to the house, it relieves the need of erecting one or both antenna supports. The antenna should not be less than 30 feet above the ground and its length should be about 75 feet. (See Fig. 1.) While this figure indicates a horizontal antenna, it is not important that it be strictly horizontal. It is in fact desirable to have the far end as high as possible. The "lead-in" wire or drop wire from the antenna itself should run as directly as possible to the lightning switch. If the position of the adjoining building or trees is such that the distance between them is greater than about 85 feet, the antenna can still be held to a 75-foot distance between the insulators by increasing the length of the piece of rope (D) to which the far end of the antenna is attached; the rope (H) tieing the antenna insulator to the house should not be lengthened to overcome this difficulty, because on so doing the antenna "lead-in" or drop wire (J) would be lengthened.

*Details of Parts.*—The parts will be mentioned here by reference to the letters appearing in Figures 1 and 2.

A and I are screw eyes sufficiently strong to anchor the antenna at the ends.

B and H are pieces of rope ⅜ or ½ inch in diameter; just long enough to allow the antenna to swing clear of the two supports.

D is a piece of ⅜ or ½ inch rope sufficiently long to make the distance between E and G about 75 feet.

C is a single-block pulley which may be used if readily available.

E and G are two insulators which may be constructed of any dry hard wood of sufficient strength to withstand the strain of the antenna; blocks about 1½ x 2 x 10 inches will serve. The holes should be drilled as shown in Fig. 1 sufficiently far from the ends to give proper strength. If wood is used the insulators should be boiled in paraffin for about 1 hour. If porcelain wiring cleats are available they may be substituted instead of the wood insulators. If any unglazed porcelain is used as insulators, it should be boiled in paraffin the same as the wood. Regular antenna insulators are advertised on the market, but the two important types just mentioned will be satisfactory for an amateur receiving antenna.

F is the antenna about 75 feet between the insulators E and G. The wire may be No. 14 or 16 copper wire either bare or insulated. The end of the antenna farthest from the receiving set may be secured to the insulator (E) by any satisfactory method, being careful not to kink the wire. Draw the other end of the antenna wire through the other insulator (G) to a point where the two insulators are separated by about 75 feet, twist the insulator (G) so as to form an anchor as shown in Figure 1. The remainder of the antenna wire (J) which now constitutes the "lead-in" or drop wire should be just long enough to reach the lightning switch.

K is the lightning switch. For the purposes of a small antenna this switch may be the ordinary porcelain-base, 30 ampere, single-pole double throw battery switch. These switches as ordinarily available, have a porcelain base about 1 by 4 inches. The "lead-in" wire (J) is attached to this switch at the middle point. The switch blade should always be thrown to the lower clip when the receiving set is not actually being used and to the upper clip when it is desired to receive signals.

L is the ground wire for the lightning switch; it may be a piece of the same wire as used in the antenna, of sufficient length to reach from the lower clip of the

lightning switch (K) to the clamp on the ground rod (M).

M is a piece of iron pipe or rod driven 3 to 6 feet into the ground, preferably where the ground is moist, and extending a sufficient distance above the ground in order that the ground clamp may be fastened to it. Scrape the rust or paint from the pipe before driving in the ground.

N is a wire leading from the upper clip of the lightning switch through the porcelain tube (O) to the receiving set binding post marked "antenna."

O is a porcelain tube of sufficient length to reach through the window casing or wall. This tube should be mounted in the casing or wall so that it slopes down toward the outside of the building. This is done to keep the rain from following the tube through the wall to the interior.

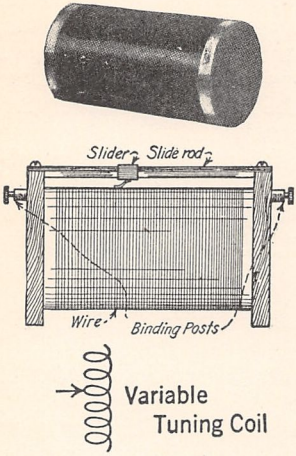
Figure 2 shows the radio receiving set installed in some part of the house.

P is the receiving set which is described in detail below.

N is the wire leading from the "antenna" binding post of the receiving set through the porcelain tube to the upper clip of the lightning switch. This wire, as well as the wire shown by Q, should be insulated and preferably flexible. A piece of ordinary lamp cord might be unbraided and serve for these two leads.

Q is a piece of flexible wire leading from the receiving set binding post marked "ground" to a water pipe, heating system or some other metallic conductor to ground except M, Fig. 1. If there are no water pipes nor radiators in the room in which the receiving set is located, the wire should be run out of doors and connected to a special "ground" below the window, which shall not be the same as the "ground" for the lightning switch. It is essential that for the best operation of the receiving set this "ground" be of the very best type. If the soil near the house is dry it is necessary to drive one or more pipes or rods sufficiently deep to encounter moist earth and connect the ground wire to the pipes or rods. This distance will ordinarily not exceed 6 feet. Where clay soil is encountered this distance may be reduced to

3 feet, while in sandy soil it may be increased to 10 feet. If some other metallic conductor, such as the casing of a drilled well, is not far away from the window, it will be a satisfactory "ground."




A SIMPLE TUNING COIL OR INDUCTANCE

The photograph shows the coil unmounted. The drawing gives details as to mounting and shows the slider by adjustment of which a greater or less part of the wire may be brought into circuit. The small drawing shows the symbol of a variable tuning coil as used in schematic diagrams, or hook-ups.

THE TUNING MECHANISM

We shall have occasion in a later chapter to deal more at length with antennæ, taking up the theory of their action, and in particular telling of newer types of wiring, including the loop aerial. But for the moment we are concerned with the putting up of a simple receiving outfit and so, having provided for the installation of the most usual type of antenna, with proper lightning-protection, we turn now to the second essential part of the receiving outfit—the tuning mechanism with which the adjustment is made that enables the receiving station to take cognizance of particular groups of electromagnetic waves, selecting out this message or that, and ignoring messages borne on waves of other lengths.

The mechanism that performs this function is of various types. For the moment we are concerned only with the simplest and most elementary of these. This consists essentially of an inductance coil, continuous with the wire of the aerial (through connection with the lead-in wire, above described), and in effect increasing the length of the antenna wire system.

The antenna wire is said to have a fundamental or natural oscillation, dependent largely upon its length. Generally speaking, the shorter the wire the more rapid its oscillations and therefore the shorter the waves with which it is in unison. But the use of the tuning coil, with a sliding connection that brings more or less of the coiled wire into the circuit at will, so modifies the oscillation period that the same aerial may be used to receive messages on waves of widely varying lengths. On occasion the tuning coil itself may be used in place of an aerial, as in General Squier's wired-wireless experiments which we shall have occasion to describe later. But for the moment we are concerned with the tuning apparatus as an adjunct of the ordinary aerial, not as a substitute.

The responsiveness of the aerial may be further modified by connecting the tuning coil with a condenser or condensers, of which we shall have more to say later. By modifying the adjustment, waves either longer or shorter than those to which the aerial would normally respond may be received and interpreted. This is obviously a matter of great importance, inasmuch as every receiving station will wish to operate, at one time or another, on varying wave lengths. Every one knows that the Federal regulations restrict the wave lengths to be used by various types of transmitting stations; but of course there is no restriction on the passive reception of messages of any type,—though there is sharp restriction on the publicity that the casual listener may give to messages not specifically intended for his ears.

Tuning coils, it will be recalled, have to do with what the electrician speaks of as "inductance," a word that is obviously a modification of "induction," which refers to the transfer of electrical current from one circuit to another by electromagnetic influence and without actual contact between the two circuits. We shall come across "inductance" everywhere as we study radio "hook-ups" or have any other dealing with radio phenomena. An

expert designates it always in his diagrams and formulæ with a capital "L."

We shall have occasion to find out a good deal more about the subject in the course of our radio studies; but here for the moment we are concerned with practicalities alone, and it will suffice to bear in mind that the tuning coil that we are connecting with the antenna wires—aerial and ground—is the simplest type of inductance, and one that the very most primitive radio receiving apparatus never lacks.

We saw that the very simplest of outfits, with which young Mr. McLaughlin won his prize, as narrated in the first chapter of this book (see page 10), had a tuning coil made by winding wire, with sundry taps, about a pasteboard box. We might duplicate that coil and introduce it into the apparatus that we are now constructing.

Perhaps it may be well, however, to make a slightly more elaborate (though essentially similar) tuning coil, and for this we may follow the directions given by the United States Bureau of Standards and intended for the instruction of the novice.

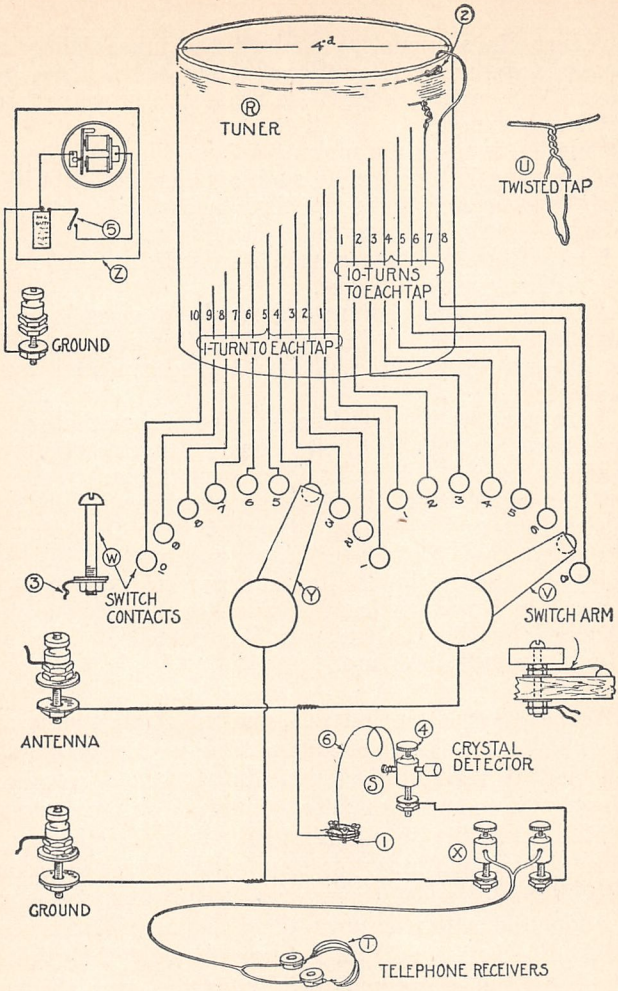
Here, then, is an account of the way in which we may make a simple yet very effective tuning coil as the second essential mechanism in the radio-receiving outfit that we are constructing:

### HOW TO MAKE A TUNING COIL

Having supplied oneself with a piece of cardboard tubing 4 inches in diameter and about ½ pound of No. 24 (or 26) double cotton covered copper wire, one is ready to start the winding of the tuner.

Punch two holes in the tube about ½ inch from one end as shown at 2 on Fig. 3. Weave the wire through these holes in such a way that the end of the wire will be quite firmly anchored, leaving about 12 inches of wire free for connections.

Start with the remainder of the wire to wrap the sev-




OUTLINE DRAWING OF THE SIMPLE CRYSTAL-DETECTOR RECEIVING SET

This drawing constitutes, in effect, an elaborate hook-up. The small drawings give details of the buzzer test and the method of twisting the wire to form a tap.

eral turns in a single layer about the tube, tightly and closely together. After 10 complete turns have been wound on the tube hold these turns snugly while a tap is being taken off.

This tap is made by making a 6 inch loop of the wire and twisting it together at such a place that it will be slightly staggered from the first tap. This method of taking off taps is shown quite clearly at U, Fig. 3.

Proceed in this manner until 7 twisted taps have been taken off at every 10 turns.

After these first 70 turns have been wound on the tube then take off a 6 in. twisted tap for every succeeding single turn until 10 additional turns have been wound on the tube.

After winding the last turn of wire anchor the end by weaving it through two holes punched in the tube much as was done at the start, leaving about 12 inches of wire free for connecting. It is to be understood that each of the 18 taps is slightly staggered from the one just above, so that the several taps will not be bunched along one line on the cardboard tube. (See Fig 3.)

It would be desirable after winding the tuner as just described, to dip the tuner in hot paraffin. This will help to exclude moisture.

We have just seen that the function of the tuning coil is to change the electrical status of the receiving antenna; and that it accomplishes this function in a relatively simple or elementary manner. In effect, it lengthens the aerial. It remains to note that substitutes for the tuning coil may be found in types of apparatus consisting essentially of double coils of wire, separately wound; with one coil adjusted within or near the other, so that the electrical current passing from the aerial through the primary coil exerts an electromagnetic influence over the secondary coil.

One such substitute for the simple tuning coil is known as a loose coupler. Others are the vario-coupler, the variometer, the honeycomb coil, and the spider web coil.

We shall have occasion to examine these in detail in a later chapter. Here it will suffice to note that the variometer and vario-coupler are made to modify the electric current by changing the relative positions of the two coils through rotating the inner coil about its axis so that the two magnetic fields developed tend to support or neutralize each other, increasing or decreasing induction thereby; and that the loose coupler accomplishes the same end by withdrawing the inner coil more or less from the outer.

The reader who is familiar with the action of induction coils will get an inkling of what is implied; the novice may advantageously take the couplers of various kinds for granted, as types of tuning mechanisms, at this stage of the inquiry. Let it here suffice that the ability of the antenna to generate electric currents in response to the flow of the radio waves along it is modified by one or another of these tuning mechanisms; and that the current, passing on toward the receiving telephones, must now be brought to the third essential part of the simple radio receiving mechanism, the crystal detector.

This is a little piece of mineral that we may purchase for perhaps twenty-five cents; but it plays so wonderful a part in our enterprise that we must pause from the construction of our receiving outfit long enough to make inquiry as to just what the little crystal is to be called on to do.

### THE ALL-IMPORTANT DETECTOR

In order to answer the question, we have first to recall that the electrical current generated in the aerial by the impact of the electromagnetic or radio waves is a high-frequency current of exceedingly rapid alternations or oscillations.

This is interpreted as meaning that the current flows first in one direction and then in the other, such alternation taking place at speeds that are inconceivably rapid,

even though they can be measured. Each change in the current may be thought of as representing the passing of an electromagnetic wave along the aerial; and as all electromagnetic waves move at the same speed (300,000,000 meters per second), it is obvious that the shorter the waves the more frequent will be their successive impact and therefore the more rapid the oscillation of the current in the receiving mechanism.

The short waves with which the amateur ordinarily works represent oscillations of from a million to two million cycles per second in the transmitting antenna, and of course set up corresponding oscillations in the tuned receiving antenna.

And even the longest radio waves represent oscillations of such high frequency that no telephone receiver can be made to respond to them, because they perpetually change their direction before the diaphragm of the receiver has time to begin to move.

Even if a diaphragm could be constructed of sufficient sensitiveness to respond directly to the impact of the radio-frequency waves, it would have no practical utility, as the waves it would generate in the air would be far too short to make audible impression on the human ear-drums. A fairly sensitive ear does not respond to air pulsations of higher rate of frequency than 10,000 per second, and ordinary sound waves are only a fraction as rapid as that.

So it is obvious that the waves which we have followed in imagination along the wires of the aerial and through the tuning apparatus must be changed from radio-frequency to what is called audio-frequency before the ears at the telephone receivers can hear any sound whatever. It may fairly be said that the apparatus which accomplishes this metamorphosis—making it possible to interpret the electromagnetic waves of enormous frequency in terms of sound waves of relative low frequency—is the most wonderful part of the entire radio mechanism.

To the apparatus that accomplishes this, the name of detector is given. As Professor Morecroft has suggested, the name is not altogether appropriate; for the apparatus does not detect anything, but only permits the electric current to flow in such a way that the telephone diaphragm responds to it so that the human ear can presently detect its effects. But the name is convenient, and it is universally employed.

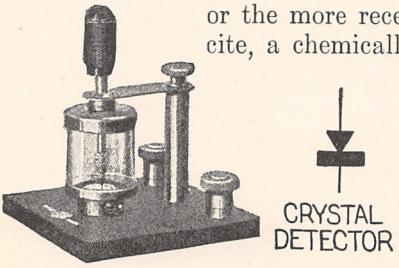
Names aside, the function of the detector is very definite and theoretically simple. That function is to act as a sort of gate-keeper, permitting half the pulsations of the generating current to pass, and denying admission to the other half. The pulsations that pass are, of course, those (theoretically) moving in one direction; those that are rejected are the ones moving in the opposite direction. Something like a million times per second the detector must exercise its selective choice; and the result of its action will be that, whereas an alternating current of enormously high-frequency approached it on one side, a direct current—flowing in one direction—leaves it on the other side.

And this direct current will flow and cease to flow in pulsations corresponding to the groups of electromagnetic waves that came from the transmitting station at intervals determined by the pulsations of the transmitting telephone's diaphragm.

Stated otherwise, the successive pulsations that come from the detector will be "rectified" to form a direct current, still modulated to represent the voices or musical sounds sent by the transmitting radiophone. This is the weird metamorphosis that the radio detector has brought about.

Strangely enough, there are several quite different types of apparatus that can accomplish this miracle. By far the most important of these is the electron tube, or audion, which we shall have occasion to examine in detail presently. But at the moment we are considering the

simplest type of radio-receiving apparatus, and in this, as we know, the function of detector is performed not by vacuum tube but by a little fragment of mineral technically spoken of as a crystal. The particular crystal employed may be a bit of mineral called galena, which is a compound of lead and sulphur obtained from mines; or it may be an artificial product called silicon, a product of the electric furnace; or carborundum, of similar origin; or the more recently introduced radiocite, a chemically treated crystal having burnished appearance that is said to be more sensitive even than galena.




THE CRYSTAL DETECTOR

The photograph shows one of many methods of mounting the crystal detector. In this instance, it is enclosed in a glass tube, so that the catwhisker and the surface of the crystal itself may be protected. The symbol is the one universally employed in schematic diagrams, or hook-ups.

Each of these crystals has the extraordinary property of letting an electric current pass much more freely in one direction than in the opposite direction. The difference in permeability may be as 400 to 1; which is practically equivalent to saying that the crystal permits the current to pass in one direction only. It is this property that enables the crystal to select every other pulsation of the alternating current, rejecting the intermediate pulsations.

Since this selective quality is inherent in the molecular structure of the crystal, it matters not at all how rapid may be the alternations. Whether the cycle is a thousand per second or a million per second, the crystal permits only the forward-moving pulsations, so to speak, to pass; rejecting absolutely, or all but absolutely, the retrograde pulsations.

I shall have a good deal to say in another connection about the wonderful implications of this strangely manifested selective action, which is utterly at variance with the non-selective action of electric conductors in general. Here it suffices to observe that the little crystals that can thus rectify an alternating current give us a choice of materials for a detector that is the final agency but one in translating electromagnetic waves into speech sounds,—enabling us to hear the inaudible.

### THE RADIO TELEPHONE RECEIVERS

The final mechanism in the performance of the miracle is the one portion of the entire apparatus that has, to casual observation, the appearance of familiarity; for in its essentials it is a telephone receiver, differing only in details and not in its principle of action from the receiver of the telephone that symbolizes the genius of Alexander Graham Bell in every household.

In most of our minds the word "wonderful" is more or less synonymous with the word "unusual." But an exception must perhaps be made in the case of the telephone. What thoughtful person does not marvel at it, even though he may use it many times a day?

The telephone receiver of radio is neither more nor less wonderful than the familiar receiver of wired telephony. Each consists essentially of a diaphragm of metal that is made to oscillate by the fluctuations in a magnetic field brought about by modifications in an electric current. The practical difference is that, for the ordinary telephone receiver, the magnet coils are wound to have a total joint resistance of about 75 ohms; whereas, for radio signals, the amount of current available being relatively minute, the coils are wound to have a joint resistance of from 1,000 to 3,000 ohms, or even more.

Ignoring these details for the moment, we find ourselves provided, to complete the equipment of our radio-

receiving apparatus, with a pair of radio telephone receivers with a looped spring to clamp them lightly on the head.

Thus we have provided all the essential parts of our proposed radio-receiver. The antenna has been erected; tuning coil has been made; crystal detector and a pair of head 'phones have been purchased.

It remains to assemble the parts, and wire them together, in proper relations. For details as to this, let us turn again to the Bureau of Standards experts for instructions.

### HOOKING UP THE OUTFIT

We have first to construct the upright panel shown in Fig. 4. This panel may be a piece of wood approximately ½ inch thick.

The position of the several holes for the binding posts, switch arms and switch contacts may first be laid out and drilled. The "antenna" and "ground" binding posts may be ordinary ⅛ inch brass bolts of sufficient length and supplied with three nuts and two washers. The first nut binds the bolt to the panel, the second nut holds one of the short pieces of stiff wire, while the third nut holds the antenna or ground wire as the case may be.

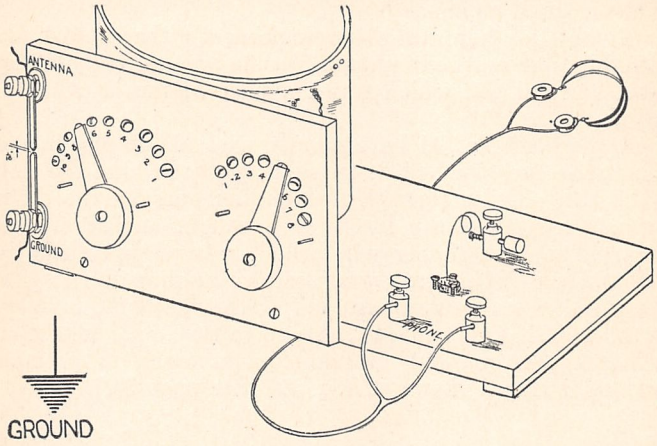
The switch arm with knob shown at V, Fig. 3, may be purchased in the assembled form or it may be constructed from a thin slice cut from a broom handle and a bolt of sufficient length equipped with four nuts and two washers together with a narrow strip of brass somewhat as shown.

The switch contacts (W, Fig. 3) may be of regular type furnished for this purpose or they may be brass bolts equipped with one nut and one washer each or they may even be nails driven through the panel with an individual tap fastened under the head or soldered to the projection of the nail through the panel. The switch contacts should be just close enough that the switch arm will not drop between the contacts but also far enough apart that the switch arm can be set so as to touch only one contact at a time.

The telephone binding post should preferably be of the set screw type as shown as X Fig. 3.

### INSTRUCTIONS FOR WIRING

Having constructed the several parts just mentioned and mounted them on the wood base, one is ready to




THE MOUNTING OF A SIMPLE CRYSTAL-DETECTOR SET

This is merely a somewhat more pictorial drawing of the set already shown in outline. The switch-arms and the switch contacts are shown mounted on a vertical panel, and the tuning coil itself, with the crystal detector on a horizontal panel. The wire connecting with one side of the structure is underneath the horizontal panel. The catwhisker is shown in the picture. The crystal detector itself is mounted without any protection.

connect the several taps to the switch contact and attach the other necessary wires.

Scrape the cotton insulation from the loop ends of the sixteen twisted taps as well as from the ends of the two single wire taps coming from the first and last turns. Fasten the bare ends of these wires to the proper switch contacts as shown by the corresponding numbers in Fig. 3. One should be careful not to cut or break any

of the looped taps. It would be preferable to fasten the connecting wires to the switch contacts by binding them between the washer and the nut as shown at 3, Fig. 3.

A wire is run from the back of the binding post marked "ground" (Fig. 3) to the back of the left-hand switch arm bolt (Y), thence to underneath the left-hand binding post marked "phones."

A wire is then run from underneath the right-hand binding post marked "phones" to underneath the binding post (4, Fig. 3), which forms a part of the crystal detector.

A piece of No. 24 bare copper wire about 2½ inches long, one end of which is twisted tightly around the nail (the nail passing through the binding post 4), the other of which rests gently by its own weight on the crystal (1). The bare copper wire which was wrapped tightly around the three brass wood-screws holding the crystal in place is led to and fastened at the rear of the right-hand switch arm bolt (V), thence to the upper left-hand binding post marked "antenna." As much as possible of this wiring is shown in Fig. 3. [See page 73.]

## DIRECTIONS FOR OPERATING

After all the parts of this crystal-detector radio receiving set have been constructed and assembled the first essential operation is to adjust the little piece of wire, which rests lightly on the crystal, to a sensitive point. This may be accomplished in several different ways; the use of a miniature buzzer transmitter is very satisfactory.

Assuming that the most sensitive point on the crystal has been found by the method described in the paragraph below "The Test Buzzer," the rest of the operation is to get the radio receiving set in resonance or in tune with the station from which one wishes to hear messages.

The tuning of the receiving set is attained by adjust-

ing the inductance of the tuner. That is, one or both of the switch arms are rotated until the proper number of turns of wire of the tuner are made a part of the metallic circuit between the antenna and ground, so that together with the capacity of the antenna the receiving circuit is in resonance with the particular transmitting station. It will be remembered that there are 10 turns of wire between each of the first 8 switch contacts and only 1 turn of wire between each 2 of the other contacts. The tuning of the receiving set is best accomplished by setting the right-hand switch arm on contact (1) and rotating the left-hand switch arm over all its contacts.

If the desired signals are not heard, move the right-hand switch arm to contact (2) and again rotate the left-hand switch arm throughout its range. Proceed in this manner until the desired signals are heard.

It will be advantageous for the one using this radio-receiving equipment to find out the wave frequencies (wave length) used by the radio transmitting stations in his immediate vicinity.

*The Test Buzzer.*—(Z, Fig. 3.) As mentioned previously, it is easy to find the more sensitive spots on the crystal by using a test buzzer. The test buzzer is used as a miniature local transmitting set. When connected to the receiving set as shown at Z, Fig. 3, the current produced by the buzzer will be converted into sound by the telephone receivers and the crystal, the loudness of the sound depending on what part of the crystal is in contact with the fine wire.

To find the most sensitive spot connect the test buzzer to the receiving set as directed, close the switch (5, Fig. 3) (and if necessary connect the buzzer armature so that a clear note is emitted by the buzzer), set the right-hand switch arm on contact point No. 8, fasten the telephone receivers to the binding posts marked "phones." Loose the set screw of the binding post slightly and change the position of the fine wire (6, Fig. 3) to several positions of contact with the crystal until the loudest sound is heard in the phones, then tighten the binding post set screw (4) slightly.

And so at last everything is in readiness, and we are prepared to "listen in" on any concert or lecture or conversation with which the ether of our environment chances to be vibrant. The electromagnetic waves are no longer to invade our domiciles and flow through our bodies unchallenged. We have set a trap for them, and in future we shall intercept at least a part of them, and witness the miracle of their transmutation from mystic vibrations of the world of ether to throbbing pulsations of the every-day world of material reality.

This miracle will soon become for us a commonplace of daily experience; but it will still remain a miracle.

## CHAPTER IV

## GETTING GOOD RESULTS—AND BETTER

HAVING followed the direction given in the preceding chapter, we find ourselves, then, equipped with a workable radio-receiving telephone outfit. It is an outfit of simple character, to be sure, but it contains all essential parts: (1) antenna system; (2) tuning coil; (3) crystal detector; (4) telephone ear pieces.

The proof of the pudding is in the eating. So if we doubt whether so absurdly simple a mechanism as we have made out of a pasteboard box and a coil of wire can really bring us messages out of the air, we have but to clap the telephone receivers over our ears,—and listen. If we are dubious, our skepticism is perhaps excusable. It does seem an unlikely thing indeed that an absurd little pasteboard box, plucked from the wastebasket, should be able to talk to us, simply because we have wound a wire about it and hitched this wire to a metal wash line up on the roof on one side and a pair of telephone ear pieces on the other, with a foolish little fragment of a pebble in between.

There isn't even a cover on the top of the pasteboard box, to help out the illusion that a Jin, like the one that the Arabian Night's fisherman found in the bottle, may be hidden inside.

It would be a very unsophisticated person indeed who could be persuaded that a simple collection of junk like that, put together before his very eyes, and standing on the table with no chance to hide anything, could be made to talk. If there were an electric battery or two hitched to it—perhaps. For electricity can do most anything.

But there isn't even a dry cell, like the one that rings the call bell, connected with this ridiculous outfit.

And yet when we put on the telephone ear pieces, the miracle happens. Sounds come to our ears—sounds that were not in the air at all before we put on the head piece; sounds that disappear when we take the head piece off. We readjust it and listen eagerly.

Perhaps the sounds are only sundry hissings and buzzings that appear to have no particular meaning—more or less like sounds that we sometimes hear in the ordinary telephone receiver, when, as we are accustomed to say, the "wires are crossed." Or there may be little creakings and clatterings that intermit in a fashion suggesting in their sequence if not in their tone-character the clattering of keys we have heard in a telegraph office.

More or less automatically we reach out and begin to play with the little levers or switches that can be revolved across the contacts on the panel, each of which, as we know, taps a different coil of the wire on the pasteboard cylinder.

As we turn the knobs, our ears give us assurance that these are the veritable keys to the situation. Sliding the contact this way and that, we modify the character of the sounds we hear. Now there is more buzzing; now there is less. This way there is hissing and that way a crackling sound. Now, as we move this lever to the left and that one to the right a point or two, of a sudden there is faint intimation of voice-sound, quite as if one were listening over an ordinary telephone. A little further manipulation and the voice is clearer, louder. And now—miracle of miracles!—we hear it clearly, plainly. Not exactly as if one were listening to a speaker actually at hand, to be sure; but nevertheless a voice, saying words that we can understand, speaking as clearly as a voice often sounds over the telephone.

By further manipulation of the levers, we may be able to make the voice still clearer; the extraneous sounds less

disturbing. Somewhere—let us say with the left-hand switch on tap 4 and the right-hand switch on tap 7—the voice is of maximum clearness, the extraneous sounds are at a minimum. We are hearing very well indeed. Now the apparatus is "tuned" to receive the particular wave lengths on which the voice to which we are listening is being broadcasted.

And so skepticism vanishes. The little pasteboard box has proved itself. The Jin is still invisible,—as a Jin should be,—but we can no longer doubt its presence. We settle back and listen, and when we have sufficiently recovered composure to give attention to what we are hearing we find that some one is telling us the result of a ball game. And then, while we still listen in dazed wonderment, some one says that a chapter from "Alice in Wonderland" will be read for the children.

The reading proceeds—as if the reader were at the other end of the room where we sit, instead of miles away—and is finished. Then there is a talk on welfare work, by a reformatory superintendent; and then we are apparently in a church listening to a school quartet; and then at the opera hearing "Rigoletto."

The thing is still almost unbelievable; but like many another almost unbelievable thing, in this age of applied science, it is simply and irrefutably true. Following simple directions, and using the most commonplace material, with our own hands we have done a miracle.

### A WORD ABOUT HOOK UPS

All in all, then, we have every reason to be satisfied. Magical results have attended our enterprise. The end we had in view is accomplished. We are intercepting the ethereal messengers. We are "hearing things" in the air.

But we shall soon learn with radio, as with every other worth-while enterprise, an apparent ending is in reality only a new beginning. We shall not long be satisfied

with our simple radio-receiving outfit, whatever its efficiency. We shall learn that our neighbors and friends are sometimes getting better results than ours. They hear things that we cannot hear; or they hear them more clearly, less disturbed by extraneous noises. And, naturally enough, we shall become dissatisfied with our own results and wish to emulate or outdo our neighbor. How shall we go about it?

First of all, we may advantageously study the simple radio-receiving apparatus that we have made, from a slightly different standpoint. We shall do well to inquire whether we fully understand exactly how and why it operates. It is no longer a question of Jins or genii, but of the practical interpretation of electromagnetic waves and electric current.

Mystery still lurks about the apparatus; nor, let us hope, will it ever vanish utterly. But we are able now, on occasion, to cease from wonderment long enough to assume the critical attitude of the investigator.

We are able to assure ourselves that, after all, what has happened is merely that certain electromagnetic waves rippling through the ether from a distant radio transmitting station have set up an electric current in the antenna we erected, and that this current has rushed along the "lead-in" wire as an electric current will, and circled such parts of the coil on the pasteboard box as the switch-contacts permitted it to do; and then continued its course by way of the "catwhisker" and the crystalline till it reached the telephone ear pieces and made the magnets there fluctuate, vibrating the diaphragm; and then—since an electric current must always complete the circuit,—run down along the wire to the "ground" and so at last to earth.

To complete the mental picture, we may imagine if we choose that the electric current which has made this strange journey through our radio apparatus, and left its message in our ears, completes its journey by sending

vibrations back through the earth all the way to the transmitting radio station, re-entering there by way of the ground. Or, if that seems too fantastic, we may think of our grounded current as in effect completing a circuit with our own aerial, not by actual flow of electrons, but by electrostatic communion through the air.

It is worth while to give thought for a moment to this final journey of the electric current, because by so doing we are made to understand why it was necessary that we should "ground" the antenna wire. We are more and more concerned, however, from a practical standpoint, with that part of the journey of the electric current that was made within the limits of the little radio-receiving apparatus on the table before us. If we have a clear understanding of that, we shall be prepared to modify and improve the apparatus itself.

To that end we may advantageously draw a diagram of the apparatus that will in effect constitute a road-map showing the journey of the electric current that brings us radio messages. This electric current, as we know, was generated in the aerial; and, as we have just noted, it passes ultimately through "ground" wire and water pipe to the earth. Our diagram must show the exact passage between aerial outfit and ground terminus.

Such a map of radio highways is called by those who wish to speak of it respectfully a "circuit diagram." By the American fan, it is dubbed a "hook-up." The name is one to remember, for it will confront us everywhere in radio literature; and the "hook-up" diagrams themselves will come presently to have for us the fascination of beautiful pictures.

No radio expert cares much about the physical appearance of your outfit. You could scarcely get him to glance at a photograph of it, though you might think it a very pretty picture. But he will eagerly scan the system of bald lines, however crudely drawn, representing the hook-up. A glance at that will tell him more than could

possibly be learned by the most careful scrutiny of a photograph.

In case of an elaborate mechanism, the hook-up that represents it may tell more at a glance than could be learned by a half hour's careful scrutiny of the mechanism itself.

Like other maps and diagrams, the hook-up is of course a highly conventionalized drawing. It is in effect a set of hieroglyphics. For the sake of simplicity, and purpose of convenience, radio experts have agreed upon signs and symbols to represent the different parts of the radio apparatus. Thus it is possible to make a very simple outline drawing, which is quite unequivocal in meaning, without the use of written words.

A glance at the diagram here presented (Fig. 1) will serve better than any description to show what the hook-up hieroglyphics are like. This diagram is the hook-up of the radio apparatus we have constructed, and are now considering. We see at once how it reveals the essentials of the wire-system connecting antenna, tuning coil, crystal detector, head telephones, and ground into a circuit for the message-bearing electric current.

About the only comment called for here is that the paths representing the wires connecting different parts of the apparatus are drawn as straight lines; whereas in reality the wires of a radio apparatus are practically always more or less looped or curved, and preferably so, since parallel wires conveying electric currents exert a mutual disturbing influence through electromagnetic induction, a so-called "hysteresis," with which we have no further present concern. It is obviously convenient to make the lines straight in the hook-up picture; but it is well to know that we should avoid paralleling lines, so far as possible, in constructing actual radio outfits. As a rule one does not see much of straight wires in a radio outfit. About the only exceptions are the aerial and the short connections within the compact body of the re-

ceiving apparatus. It is not straight wires, however, but only parallel wires that are to be avoided.

Having examined the diagram of our radio receiver, and compared it with the apparatus itself until we quite

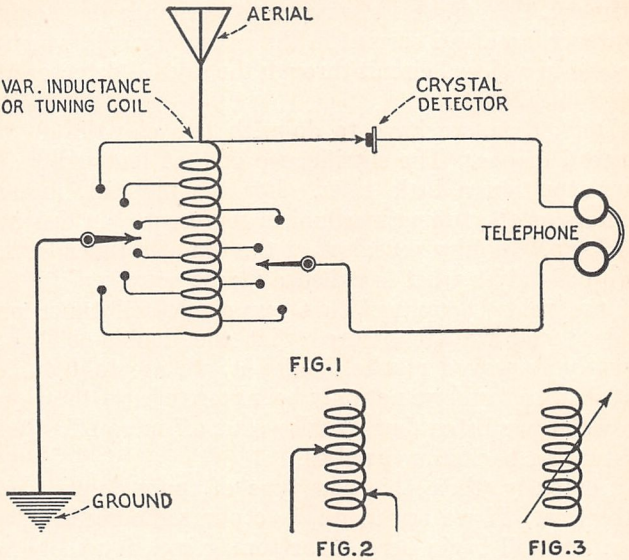



FIG.1



FIG.2



FIG.3

SCHEMATIC DIAGRAM OR HOOK-UP OF SIMPLE CRYSTAL-DETECTOR RECEIVING SET

This diagram represents the simple receiving set already depicted. A glance will suggest the convenience of the conventional symbols.

Figures 2 and 3 show alternative symbols for representation of the variable tuning coil. The arrowheads in figure 2 may represent either taps or sliders on the coil. The arrow across the coil in figure 3 symbolizes the variability of the tuning coil, which may be produced either by taps or by sliders. Because of its convenience, the symbol shown in figure 3 is very generally used.

clearly understand it, we may turn to a second hook-up which will be seen at a glance to show one striking departure from the first diagram.

The point of departure is in the tuning coil, which now

appears as two coils apparently not in physical contact. You surmise that we now have to do with an induction coil. Such is the fact. The electric current coming from the antenna will be passed through one coil, called the primary, and make its way to the ground; developing, however, an allied current in the secondary coil, which is passed in a closed circuit through the crystal detector and head telephones.

Here, then, we have to do with two electric circuits instead of one. The significance of that fact will claim our attention a little later. For the moment, interest centers on the tuning mechanism represented in this new hook-up. Inquiry reveals that the use of a tuner having two coils gives what is called a "loose coupling" instead of the "close coupling" that our single-coil tuner provided; and we are assured that the double-coil gives greatly improved results. With it, we are told, tuning is "sharper," and we not only hear more clearly the voices to which we listen. but we also shut off more effectively disturbing background noises.

Obviously, then, this new type of tuner deserves our attention. If we are to improve our radio receiver, we may as well begin here. Our tuning coil, it will be recalled, is merely wired into the antenna circuit by joining its end wires with aerial and ground. It would obviously be a simple matter to disconnect these wires and substitute some other tuning mechanism. Now we are made aware that better types of tuning mechanisms are available. The one we constructed had the merit of great simplicity. Others are more complex, but inasmuch as they are also more efficient, we must know about them. In an earlier chapter, some of these were named. Let us now examine them somewhat in detail.

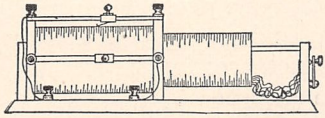
### IMPROVING THE TUNING APPARATUS

The more familiar of these substitute tuning devices, or inductances, are named: (1) loose coupler, (2) vario-

coupler, (3) variometer, and (4) honeycomb coil. There is a somewhat less familiar type called spider-web or spider-lattice coil.

Let me hasten to explain that these various apparatuses, with their rather disconcerting names, are in reality contrivances of relative simplicity, much less terrifying to encounter than their names might suggest.

They are all modifications of the simple induction coil which is one of the commonest of electrical devices,—a little induction coil being, for example, the essential apparatus that rings your door-bell when you push the



THE LOOSE-COUPLER AND ITS SYMBOL

The small or secondary coil slides in and out of the primary coil. Further variability of current is attained by the sliding contact on the primary coil.

button. When you push the button on your desk, wishing to summon the office boy, it is the little induction coil, stored in some out-of-the-way corner along the electric circuit, that changes the direct current (D.C.) from the electric battery into an alternating current (A.C.) that vibrates the buzzer. Also there is a little induction coil in the telephone box fastened on your desk or against the wall—else the telephone bell would not ring.

The induction coil is, then, an old and familiar friend, however we may have failed to cultivate its intimate acquaintance. And now we have occasion to invoke its aid for the betterment of our radio-receiving telephone outfit. Whether we decide to supplant our simple tuning coil with a loose coupler or a variometer or a vario-

coupler or a honeycomb coil, or a spider-lattice coil, the substitute apparatus will still be an induction coil, of which the essential principle is that an electric current in one of its parts is made to generate a new current in another of its parts by "induction"—that is to say, by electromagnetic influence, operating through the ether and without physical contact (except in case of the variometer) between the two parts of the apparatus in question.

In every radio apparatus but the very simplest, there is at least one such inductance; and there may be several or many inductances of various types, in the more complicated radio apparatus, as we shall see in due course.

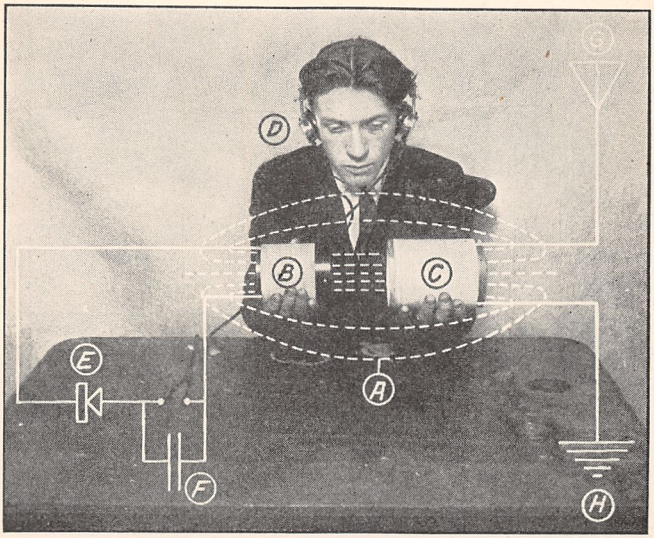
For the moment, however, we are concerned only with a simple inductance to take the place of our tuning coil, though we shall perhaps find presently that we wish to combine two or more inductances for the further perfection of the tuning mechanism.

One great merit of an induction coil is that it can change certain essential characteristics of an electric current. In the case of a door-bell and buzzer, a direct current was changed to an alternating one, as we saw. In the case of the radio-receiving mechanism, the induction coil can modify current that comes from the aerial in such wise as to change the receptiveness of the aerial, making it responsive to this or that length of radio waves. In other words, tuning it.

Stated otherwise, a little more technically, the induction coil can modify the condition already referred to as "inductance" of the antenna system.

Of course the simple tuning coil that we have already installed in our radio-receiving apparatus does this also; but the substitute induction coils of various types that we now have under consideration have greater flexibility of action. This is in the first instance because the two coils that compose any induction coil may be varied indefinitely in the original construction as to relative

length of wire, thus radically modifying the relations of the two currents (one called primary and the other secondary, or induced); and in the second instance because the mutual relations of the electromagnetic fields of the



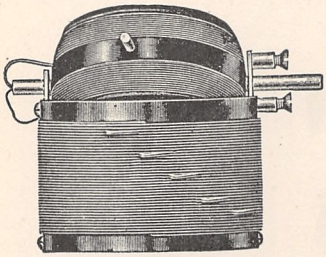

Courtesy "Popular Radio"

INDUCTANCE ILLUSTRATED WITH A LOOSE-COUPLER

The primary of the loose-coupler (*C*) is hooked up in the antenna circuit. The secondary (*B*) is hooked up with the detector-telephone circuit. There is no physical connection between the two coils. The dotted line indicates the mutual electro-magnetic, or inductive influence.
*D*, telephones; *E*, crystal detector; *F*, fixed condenser shunted across the telephone; *G*, antenna; *H*, ground. We reproduce this interesting illustration, giving verisimilitude to a simple hook-up, through the courtesy of *Popular Radio*.

two coils may be modified at will by physical manipulation, thus changing the relations of the two currents, to meet the needs of the moment, in tuning for one wave length or another.

In the case of the loose-coupler, for example, the wire-wound cylinder constituting the secondary coil is relatively small, and can be slipped inside the larger wire-bound cylinder constituting the primary. When the secondary coil is thus slipped into the hollow of the larger coil, it will obviously come most directly under the influence of the electromagnetic field generated by the electric current passing through the primary; and when it is partly or wholly withdrawn, it will just as obviously be under less direct influence.



THE VARIO-COUPLER

This popular form of loose-coupler has the secondary coil adjusted so that it rotates instead of being pushed in and out as with the older type of loose-coupler. The primary coil is tapped, to permit variation in the number of turns of wire brought into the circuit.

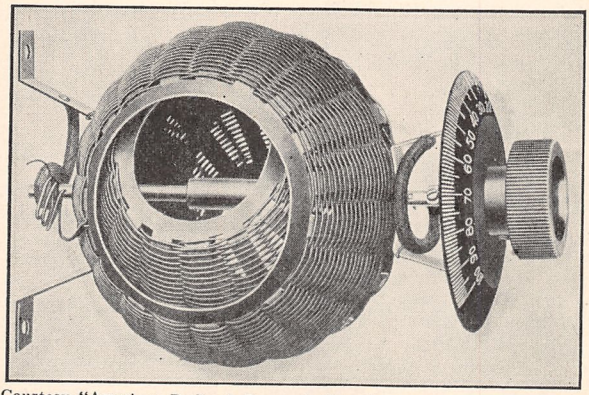
The relation between the two coils being thus adjusted at will, the transfer of energy from the primary coil to the secondary may be indefinitely modified; and in the same measure the inductance of the antenna system as a whole is modified.

In the case of the relatively gigantic loose couplers used in a transatlantic radio-telegraph outfit, the secondary coil is sometimes removed from the primary to a distance of several feet in order to secure optimum conditions of resonance; or, stated in practical terms, in order to make the signals most clearly audible.

Our present concern is with a loose coupler of dimensions measurable in inches; but the principle of action is the same whatever the size of the mechanism.

The vario-coupler and the variometer differ from the loose coupler as to details of operation rather than as to essentials. In each case the secondary coil is adjusted within the cylinder of the primary coil, on a fixed pivot,

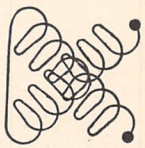
which permits the rotation of the secondary so that its wires shall cut the magnetic field established by the primary in varying relations. The direction of the axis of a wire that is to receive an induced current in its relation to the lines of force of the electromagnetic field, is well known to be an important factor in determining



Courtesy "American Radio & Research Corp."

THE VARIOMETER AND ITS SYMBOL

The variometer is a form of coupler in which the secondary coil revolves within the primary coil. There is wired connection between the two coils which is not the case with the other couplers. As the inductive influence can be definitely modified by rotating the interior coil, it is not necessary to tap either coil.



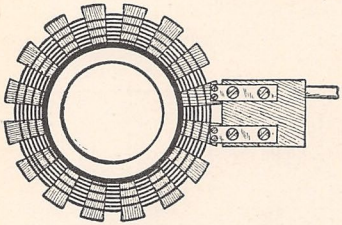
VARIOMETER

the character of the induced current. This principle is utilized, as has just been stated, in the vario-coupler and the variometer.

The same principle, it may be added, is utilized to some extent also with the honeycomb coupler; although this apparatus introduces another element of flexibility, in that it is so constructed that different coils, both primary and secondary, may be substituted for one another at

will. Details as to all these matters will claim our attention in a moment.

Sooner or later you will probably wish to have a honeycomb coil, that being among the newest and in some respects the most efficient of inductances; but the older types that we have just been considering are by no means obsolete, and it is well worth while to know how to construct simple examples of each type. You may wish to use two or more of these inductances at the same time, as you develop your receiving outfit,—loose coupler and variometer, for example; or a vario-coupler and one or two variometers.



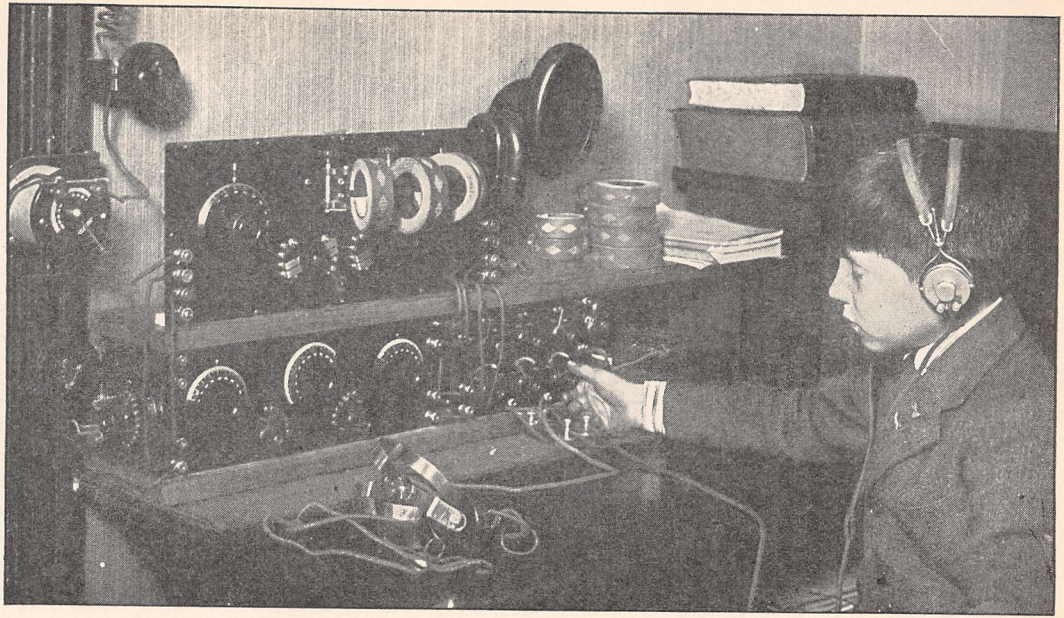
SPIDER WEB COIL

Sometimes called spider-lattice, or pancake coil. Two or three of these coils are mounted together, the inductive influence being modified by moving them apart, like the leaves of a book.

Let us then inquire just how each of these apparatuses may be constructed, beginning with the simplest example, the loose coupler.

## MAKING A LOOSE COUPLER

We shall at once gain a clear idea of the loose coupler, and a very definite notion as to how to make one, if we think of the apparatus as consisting essentially of two inductance coils such as we constructed to make the tuning apparatus of the radio receiver already in hand; one coil different from the other merely in that the tube or cylinder on which it is wound is small enough to slip inside the other cylinder. The wire on the two coils (about No. 24 or 26) must be wound in the same direction —as if the two tubes had held end to end and the winding continued from one to the other. Each is wound



A RECEIVING SET WITH HONEYCOMB COILS

Near the top of the upper panel of the receiver, three honeycomb coils in the mountings will be seen. Six other honeycomb coils, of different sizes, lie in two piles at the right; to be substituted in the mountings on occasion, to modify the wave length.

quite independently, however, and there is no wired connection between the two completed coils.

The wire used for winding may be cotton-covered or enameled, or bare wire may be used and subsequently shellaced for insulation. For convenience, the outer tube usually takes the place of our original inductance coil, being connected with antenna on one hand and ground on the other; and so constitutes the primary. There is no reason, however, why the inner tube should not be used as primary instead. The effect will be the same in either case.

Taps being taken from the primary coil, in the manner with which the making of our original coil made us familiar, these may be arranged on a panel, with switches, so that a greater or less extent of the coil wire may be brought into the primary or antenna circuit at will, for the tuning of the circuit. Here we are merely utilizing the principle and the method with which we are familiar.

An alternative method is to scrape the insulation from the wire in a line along the top of the coil, and to use a slide, or a double slide, for establishing contact, thus short-circuiting the coil at any given place or places, and producing precisely the same effect that is gained with the taps. The advantage of the sliding mechanism is that we may tap the coil at any wire, instead of only at intervals determined by the interval between taps in the original constructions.

In either case, the secondary coil will have taps taken off at intervals, during the winding. For convenience, these will be drawn through holes into the interior of the tube, and then (when the winding is finished) brought to the outside of the tube through holes at the end, and arranged in flexible contact with contact points on a panel; the object being, of course, to short-circuit the secondary coil at any desired point, thus bringing a greater or less length of its wire into the secondary circuit.

By manipulation of the contact points representing the primary coil and the secondary coil respectively, it will obviously be possible to attain greater range in tuning than could be expected of a single coil; and further flexibility is attained by sliding the secondary coil in or out and thus causing the coils of the secondary to cut through a greater or smaller number of lines of magnetic force developed by the electric current in the primary.

As a matter of course, the primary coil is mounted inflexibly at one end; and some simple sliding apparatus is provided that will permit the easy backward and forward movement of the secondary.

The end wires of the primary, as already explained, connect with antenna and ground respectively; and of course the end wires of the secondary connect with and complete the "secondary circuit" which includes the crystal detector and the telephone ear pieces. What constitutes an "end wire" in any given occasion will, of course, depend upon the point of contact established (with this or that tap) by the shift-lever on the panels.

Any one who clearly apprehends these principles can make an effective loose coupler. The flexibility of the instrument will depend merely upon the number of turns of wire and the frequency with which taps are taken off.

Specific suggestions for the construction of a loose coupler to be inserted in the apparatus already in hand are given in a second bulletin of the Bureau of Standards which will be quoted in full at the close of this chapter. Before coming to that, however, let us briefly consider the principles of construction of the alternative types of induction coils already named. We shall have occasion also to refer to another type of tuning apparatus that may advantageously be introduced to supplement the inductance coil,—namely, the condenser, without which the full advantages of the loose-coupler cannot be secured.

### MAKING VARIO-COUPLER AND VARIOMETER

It should be re-emphasized that the tuning devices known as vario-couplers and variometers are only modified forms of the loose coupler just described; which, as we know, is merely a particular type of the familiar induction coil. These newer types of couplers gained great popularity in radio work, partly because of their flexibility and efficiency, partly because of their compactness.

The outer or primary coil of the vario-coupler does not differ in any essential from the primary coil of the loose-coupler above described. It is wound and tapped in the same manner. As a matter of convenience, it is usually mounted vertically instead of horizontally, but there is no electrical significance in this.

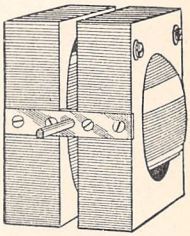
The secondary coil of the vario-coupler is wound on a cylinder or tube so short that it can be inserted crosswise into the larger tube of the primary coil, and rotated at will so that its imaginary central axis may be at right angles to that of the outer tube, or parallel with it, or at any angle between.

The actual axis of rotation of the secondary coil, when installed partly within the primary coil, is a shaft through its center, crosswise, like the diameter of a circle, which shaft at its protruding ends is pivoted through the tube of the primary coil near one end. To make this arrangement feasible, the winding of the secondary is interrupted for a little space at the middle, to make room for the pivotal rod.

It is not necessary to tap the winding of the secondary, for the current generated in it may be held to any desired relation with the current in the primary by merely revolving the secondary on its axis. When the two coils are parallel, one effect is produced; when they are at right angles (through rotation of the secondary), quite a different effect. It is a question, as already explained, of

the relation between wires of the secondary and the magnetic field of the primary, and it is obvious that nice gradations may be obtained by slight turning of the pivotal axis this way or that.

The variometer illustrates the same principle of action, and is closely similar as to method of construction. The practical difference is that the variometer secondary is usually wound on a ball-shaped tube, or the central segment of a ball, so that it can revolve within the tube of the primary; and the arrangement is such, through winding the primary also with interrupted central windings, that the secondary may be centrally mounted instead of toward the end of the outer tube as in the vario-coupler.



FAMILIAR TYPE OF VARIOMETER

This variometer differs in no essential of construction from the one previously shown, but is of more usual shape.

This arrangement obviously brings the variometer secondary even more intimately within the influence of the primary than in the case of the vario-coupler; and the opportunity for complete rotation on the transverse axis makes it possible to bring the two currents in parallel, at right angles, or directly in opposition; their magnetic fields being thus additive or mutually nugatory at will of the operator, or adjusted at any intermediate relation. It should be explained that there is actual wire connection, in series, between the two coils, and not merely connection by induction. In some forms of the apparatus, connections are made through brush contact, so that the ball may be continuously rotated without breaking the circuit. The simpler form has a flexible wire connection, permitting rotation of 180 degrees.

There are no taps on either winding of the variometer, and it is quite possible to make the apparatus at home—

after a fashion. To wind the primary coil (called "stator" when installed) is not particularly difficult, as an ordinary tube may be used, care being taken to leave a quarter-inch space at the center for the pivotal rod. The winding of the secondary (called "rotor" when installed) is more difficult if a ball or barrel-shaped tube is used; and if an ordinary piece of tubing is substituted, it must be very short or very small in order to revolve within the stator without touching it. The thing can be managed, but unless the amateur has exceptional skill, he will find it advantageous to purchase vario-couplers and variometers rather than to attempt their manufacture. They are not very expensive, in comparison with other parts of a high-grade radio-receiving outfit.

### HONEYCOMB COIL AND SPIDER WEB

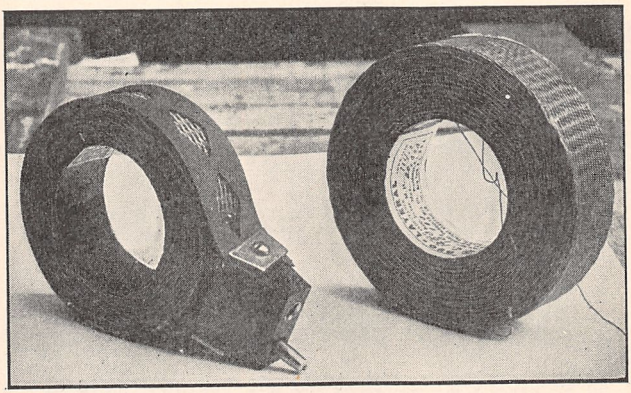
The same remark applies to the even more up-to-date couplers that go by the names of honeycomb coils and spider-web coils, respectively. Nevertheless many young amateurs do construct the honeycomb coil; and the spider-lattice is an arrangement in which some amateurs, notably those making freak sets, have specialized, in advance of the commercial manufacturers.

The type of coil of which the duo-lateral and the honeycomb coil are examples, represents a departure in winding, in that the cylinder employed is short, the wire being wound back and forth in many layers, after the manner of winding a ball. The result is a wheel-like coil, to be mounted side by side with one or more of its fellows; the mounting being flexible, so that the coils can be brought close together, as if they were one tube, or can be separated at any angle or distance. Of course a specially devised mounting is necessary.

The effect when the honeycomb coils are in operation is to establish almost any desired relation between magnetic fields. The primary coil, representing the antenna-

ground circuit, is usually mounted at one side, stationary. The secondary coil, representing the detector-telephone circuit, is mounted in the center, and a third coil may be introduced, known as a tickler coil, the function of which will be made clear to us when we have studied the electron-tube detector. With the crystal detector of our present apparatus, the tickler coil has no significance.

A unique merit of the honeycomb coil is that the indi-



HONEYCOMB COILS DETACHED

Coils similar in type to these are sometimes named duolateral. This type of coil is gaining in popularity.

vidual coils may be purchased of various sizes, adapted therefore for tuning for different wave-lengths; and one substituted for another as readily as, for example, electric lights may be changed in a socket. It is merely a matter of slipping one out and slipping the other in, circuit contact being established automatically.

The spider-lattice or spider-web, coil is an affair of very curious and novel construction, although of course introducing no new principle. The basis for the winding is a flat disc of heavy cardboard or bakelite, with sections cut centerwise from the periphery, so that what

remains forms a heavy-spoked wheel with an uneven number of segments. The wire is wound round and round, under one spoke and over the next, thus forming a lattice effect, roughly suggestive of a spider web, as the name implies.

The wheels are mounted side by side, after the manner of the honeycomb coil; the center one being used as secondary and the lateral ones as primary and tickler coil, respectively; and an arrangement made whereby the outer coils can be made to approach or recede from the center one either by mounting on a threaded shaft running through the centers of all, or by a hinge arrangement giving a fan-like effect.

A very compact receiver can be made with the use of spider-web coils, which are mounted in the way just suggested when in use, but dismounted and laid flat within the case when the apparatus is to be folded up for transportation.

### ANOTHER TYPE OF TUNER—THE CONDENSER

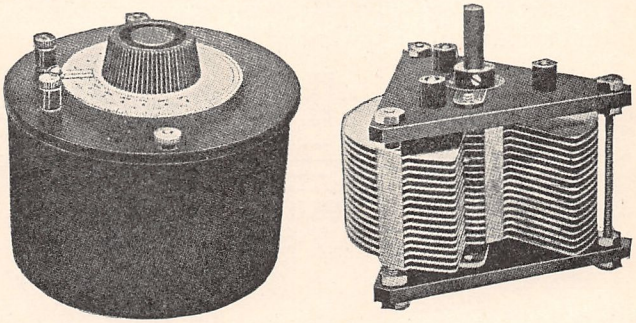
Let it be reiterated that all the various types of coils that we have examined, from the simple inductance coil to the various types of loose couplers, are devices designed primarily to modify the length, and thereby the inductance, of the antenna system. The newer forms have a degree of efficiency that gives them deserved popularity; and sooner or later every radio enthusiast will find use for them; but in the evolutionary development of the set that we have constructed, it will suffice for the moment to introduce a loose-coupler of the earlier type. This has by no means been superseded altogether, and it has the great merit of being very easy of construction. When properly used it may have a high degree of efficiency as a tuning mechanism.

It is necessary, however, in order to secure anything like maximum efficiency with any coupler inductance to

utilize also another and quite different type of tuning device to which hitherto no extended reference has been made in the course of our radio observations.

This is the device known as a condenser, of which there are two classes, one called fixed and the other variable.

There is no radio hook-up except the very most primitive that does not show at least one condenser; and most



THE VARIABLE CONDENSER AND ITS SYMBOL

The figure at the left shows the condenser in its case. The one at the right shows the condenser itself, part of the plates fixed and the other set revolving in the interspaces, with a film of air for dielectric.

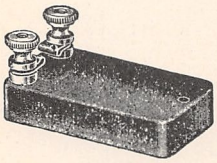
VARIABLE CONDENSER

hook-ups show two or three or more of these devices. It cannot be said that a separate condenser is absolutely essential to a receiving radio apparatus; for, as our own experience has shown, a workable receiver may be constructed without a condenser. Nevertheless the condenser is an essential part of every elaborate radio-receiving mechanism. It constitutes a fifth and final important element in the radio hierarchy,—the other four being, as we know, the antenna, the inductance coil, the detector, and the telephone ear piece.

The condenser is, indeed, to be thought of always as

complement to and co-worker with the inductance coil. As the inductance has to do with flowing electricity, the condenser has to do with stored electricity.

It has been mentioned that the tangible antenna system is, in effect, a gigantic condenser, with aerial for one plate and ground for the other, and the intervening air for buffer, or so-called dielectric, between the two. It may be added that a single inductance coil has also to some extent the effect of a condenser, different parts of its coil system acting toward one another like the plates of a condenser. Understanding this, we realize that even our primitive radio-receiving apparatus was not without power to store electricity as well as to conduct it, notwithstanding we provided for it no tangible condenser.




FIXED CONDENSER AND ITS SYMBOL

The sets of leaves of the condenser are not visible, being shielded by the case. It will be understood that a different set of leaves connects with each of the two connection-posts.

A small condenser that we shall add to this radio receiver, to give it better tuning and add to its all-round efficiency, will be connected into the secondary electric circuit. In reality, it will be expedient for us to introduce more than one condenser presently, in order to give the receiving apparatus as wide a range as possible of receptivity to waves of varying lengths, by supplementing the storage capacity of the entire system.

This storage capacity for static electricity is referred to technically as "capacity," and it is represented always by the letter C. The complementary condition of inductance (having to do with current electricity instead of static) is indicated by the letter L. In the hook-up,

as will be seen, the condenser is represented by two short broad parallel lines usually placed transversely to the wire; and the variable condenser is distinguished by an arrow cutting diagonally across the lines.

We shall have a great deal more to say about condensers, and the capacity for storing electricity that they represent, before we are through. Let it here suffice for the moment that capacity and inductance are the two fundamental factors that determine the natural period of the oscillation of any antenna system. Any two antenna systems are in harmony or resonance—that is to say will oscillate at the same rate—when the product of the inductance (measured in henries or microhenries) into the capacity (measured in farads or microfarads) of one equals the product of the same pair of complementary factors of the other.

Let it be noted that it is the product of the two factors, not either of the pairs of factors individually, that must coincide.

When there is failure of coincidence (that is to say where a receiving system is not in resonance), change in the required direction may be effected by modifying either the resonance or the capacity of the system.

And that, of course, is merely a somewhat technical way of saying that we may tune a receiving radio mechanism with aid of variable condensers no less than with the aid of inductances made variable by taps or by loose coupling.

### MAKING A SIMPLE CONDENSER

A general idea of the function of the condenser may be gained from its name. The condenser is, in effect, a receptacle into which the electricity flows for temporary storage. The presence of the condenser increases the electrical capacity of the system somewhat as an auxiliary tank might increase the capacity of a set of water pipes.

This comparison, though crude, represents a fairly permissible analogy, inasmuch as the electrical condenser contains essential parts which are not conductors of electricity, and which merely store the electrical "fluid," removing it from the flowing current as the tank removes water from the current in the pipes. The analogy is heightened if we assume that the water tank is flushed automatically when full, thus returning its contents to the circulating medium; because the electrical condenser periodically gives up its store of electricity, passing it on toward its ultimate destination.

The simplest type of condenser consists essentially of alternate layers or sheets of conducting and non-conducting material; so arranged that the ends of sheets numbers 1, 3, 5, etc., project and are connected with an electric lead at one end, and the alternate sheets (2, 4, 6, etc.) project and are connected at the other end. The conducting sheets may be of tinfoil; the non-conducting inner leaves of mica or of paraffine covered paper. For a small receiving set, the paper leaves may be about fifteen in number and about two by three inches in size. The paper must overlap the tinfoil everywhere except at the projecting end. The interleaved tinfoil sheets of one series are positively charged; those of the alternate series negatively charged.

According to theory, the electricity is not stored in the tinfoil sheets, but in the insulating medium; in this case paraffine paper, which is called a dielectric.

It is assumed that the molecules of the dielectric become polarized,—in effect made into little magnets, with the north and south poles of alternate molecules in contact, somewhat as iron filings are arranged in a magnetic field. But whatever the theoretical explanation, the fact of temporary storage of static electricity in the condenser is a matter of familiar observation and easy demonstration.

The amount of electricity that can be stored depends

upon the inherent characteristics of the particular dielectric used. This capacity is technically spoken of as the "specific inductivity" of the material, and tables are available that give the relative values of different substances, air at ordinary pressure being taken as a standard for comparison.

Among substances of high inductive value, and hence of especial utility in the making of condensers, are paraffine paper (3.65 on the scale, with paper 1.0 at air for unity), hard rubber (2.05 23.15), olive oil and sperm oil (3.00 to 3.16), sheets of pure mica (4.00 to 8.00), porcelain (4.38), cork (4.50), castor oil (4.80), and various kinds of glass, with double-extra flint glass (10.10) at the top of the list.

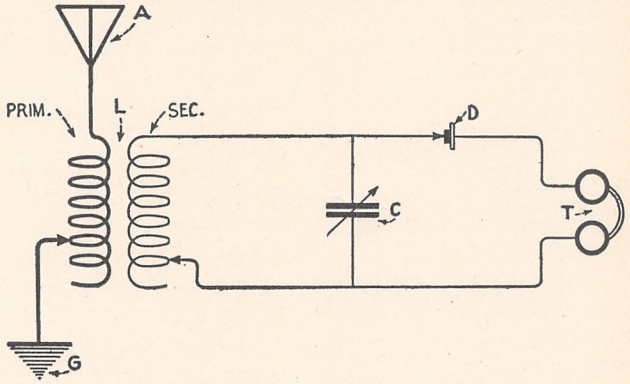
Condensers of the simple type just described are called fixed condensers, for the obvious reason that the capacity of a condenser of any given size and material can be predetermined and does not change. There is another familiar type of condenser, however, often used in the same apparatus with the fixed condenser, in which the alternate sheets or plates are so arranged that conductors and dielectrics can be separated at will, wholly or in part (as by moving the dielectric away from the sheets of metal and thus modifying the current).

Such an apparatus is known as a variable condenser. As practically arranged, its capacity may be reduced by turning a knob so that the moving plates slide out from within the alternate fixed plates. The arrangement does not change the principle of the condenser, but obviously adds to its flexibility of action, modifying the capacity of the circuit in which it is placed.

For example. High wave-lengths are tuned in by connecting a variable condenser with the aerial. A variable condenser in series with the ground lead reduces the capacity of the aerial circuit and thus tunes for short waves.

INTRODUCING THE IMPROVED TUNING APPARATUS

A hook-up is here presented which shows our improved radio-receiving apparatus as it will be when we have substituted a loose coupler for the original inductance coil, and have introduced a variable condenser in the secondary circuit. We have come to understand fully just why it is worth while to make these changes, and just what theoretical considerations make it fairly certain




HOOK-UP WITH LOOSE-COUPLER AND VARIABLE CONDENSER

that our radio apparatus will be improved thereby. Let us now consult the bulletin of the U. S. Bureau of Standards, already referred to, in which directions are given for the construction of the loose-coupler and for its placement, along with the condenser, in the radio receiver.

As will be seen, these instructions refer specifically to the changes that are to be made in the apparatus that we have already constructed,—that apparatus having been made, as will be recalled, after a model put out by the Bureau of Standards, in the interest of the novice.

This second bulletin, put out April 15, 1922, under title of "Construction and Operation of a Two-Circuit Radio

Receiving Equipment with Crystal Detector," was prepared, at the request of the States Relations Service of the U. S. Department of Agriculture, for the use of boys and girls' radio clubs. We cannot do better than to reproduce it here in full.

This pamphlet describes the construction and operation of a simple receiving set which has about the same receiving range as the one described in the first pamphlet and will respond to the same wave frequencies (wave lengths). The advantage of this set is that it is more "selective," which means that it is easier to distinguish the message from one of two radio transmitting stations when both of the transmitting stations are using wave frequencies (wave lengths) that are nearly the same. This greater selectivity is brought about through the use of two complete electric circuits, both of which are tuned to the incoming waves. This is in contrast to the single-circuit equipment, as described in the first pamphlet.

The total cost of the equipment can be kept down to about $15.00. Most of the equipment mentioned in Circular No. 120 [as quoted in the preceding chapter of this book] can also be used with this set, and the cost of the additional apparatus will be about $5.00.

### ESSENTIAL PARTS OF RECEIVING STATION

*Antenna, Lightning Switch, Ground Connections, and Telephone Receivers.*—These are completely described in Circular No. 120. The other essential part of the equipment is the receiving set which is made up of the following parts.

*Coupler (Left half of Fig. 1).*—This is composed of a fixed section and a movable section. The fixed section is made up of the coil tube P, the upright support J, the contact panel K and the base B. The movable section is composed of the coil tube S, the supporting contacts panel M and the base L. The movable section is so

arranged that the coil tube S slips inside the coil tube P when M is pushed to the left. The coil tubes are made by winding wire on cardboard tubing.

This pamphlet tells how to construct a coupler in the home. It is of course possible to purchase a coupler of the type here described at almost any store which handles radio supplies. Another type of device, called a "vario coupler," has a rotating coil. In purchasing any coupling device, care should be taken to select one which will operate satisfactorily with the condenser available, at the wave frequencies to be received.

*Variable Condenser* (*C, Figs. 1 and 2*).—The variable air condenser should have a maximum capacity rating between 0.0004 and 0.0005 microfarad (400 to 500 micromicrofarads).

*Crystal Detector* (*D, Figs. 1 and 2*).—This is essentially the same crystal detector as was described in Circular 120 except that a few improvements have been made in its construction.

*Accessories.*—Under the heading of accessory equipment may be listed binding posts, switch arms, switch contacts, test-buzzer, dry battery, and boards on which to mount the complete apparatus. The binding posts, switch arms, and switch contacts may be purchased from dealers who handle such goods or they may readily be improvised at home. The pieces of wood on which the equipment is mounted may be obtained from a dry packing box and covered with paraffin to keep out the moisture.

Care should be taken in melting the paraffin not to get it too hot and it should not be heated beyond the point where it just begins to smoke. The paraffin may be melted in a pan set in boiling water in order to eliminate the possibility of getting it too hot.

When the wood parts have been drilled and cut to size the paraffin should be applied quickly with a small brush. When cold, the excess paraffin should be carefully scraped off with a straight piece of metal such as the brass strip in the edge of a ruler.

DETAILS OF COUPLER CONSTRUCTION

*Movable Coil Tube, Coil Tube Support and Base (S, M, & L, Fig. 1).*—The coil tube S is a piece of cardboard tubing 3⅝ inches in diameter and 4 inches long. A round cardboard table-salt box which can be obtained at any grocery store is about 3⅝ inches in diameter and can be used for this purpose. One of the cardboard ends or caps should be securely glued to the box. This tube is wound with No. 24 (or No. 26) double cotton covered copper wire.

The method of winding the wire is much the same as described in Circular 120. Punch two holes in the tube ⅜ inch from the open end, as shown at R, Fig. 2. Weave the end of the wire through these holes so that it is firmly anchored and has one end extending about 10 inches inside the tube.

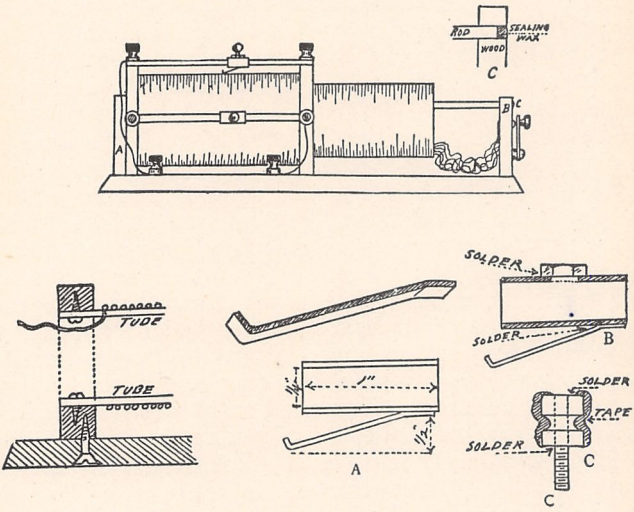
Punch a hole F about ⅝ inch from the other end (which has the cardboard cover secured to it) in line with the holes punched at R. Draw the free end of the wire through the inside of the tube and thread it out through the hole at F. Now wind on 10 turns of wire and tap off a 6-inch twisted tap, as described in Circular 120. Hold the turns tight and punch a hole B directly underneath this tap. Insert the end of the tap in the hole and pull it through the inside of the tube so that the turns are held in place. The hole for this tap should be slightly staggered from the first two holes which were punched.

Punch another hole L ⅝ inch from the other end of the tube and in line with the hole B. Thread the twisted tap out through this hole and pull it tight. Wind on 10 more turns and bring out another twisted tap; then 10 more turns and another tap; 15 turns and another tap; 15 more turns and another tap. Finally wind on 20 more turns and bring out the free end of the wire in the same manner as the taps were brought out.

The tube now has 80 turns of wire wound on it and there are 5 twisted taps and two single wires projecting through the row of holes at the closed end of the tube.

The position of the wires inside the coil tube is shown by the dotted lines.

The contact panel M (Fig. 1) which supports the coil tube is a piece of dry wood 5½ inches high, 4 inches wide and ½ inch thick. The contacts, switch arm and knob, and binding posts are described in Circular No. 120.

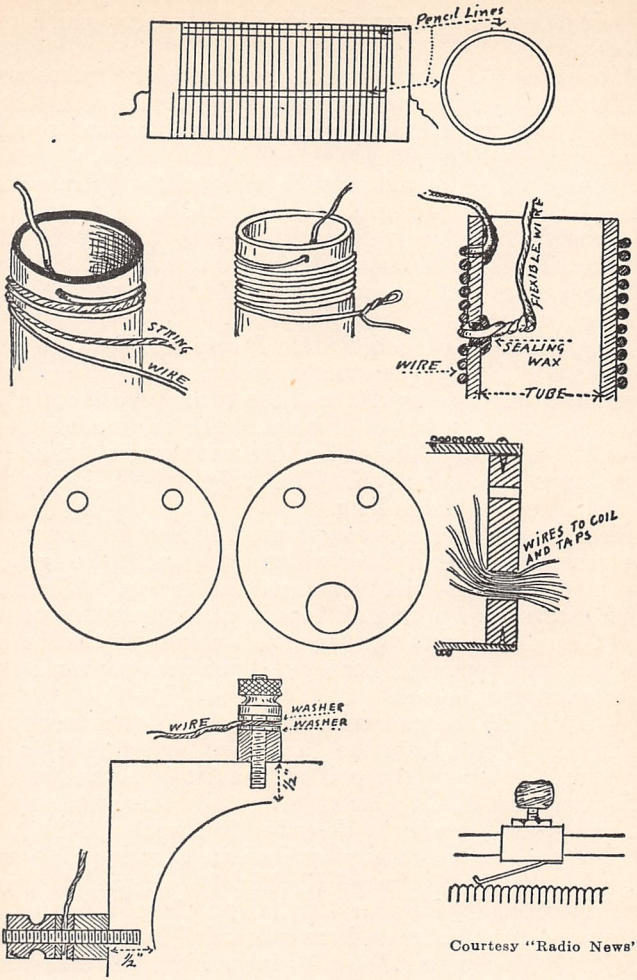



LOOSE-COUPLER, WITH DETAILS OF CONSTRUCTION

The figure of the loose-coupler is reproduced for convenience of comparison with the individual parts shown here and on the opposite page.

The end of the switch arm should be wide enough so that it will not drop between the contact points, but not so wide that it cannot be set to touch only a single contact. Having located the hole for the switch-arm bolt, the switch arm should be placed in position and the knob rotated in such a manner that the end of the contact arm will describe an arc upon which the contact points are to be placed.

The holes for the contacts should next be drilled, the




Courtesy "Radio News"

DETAILS OF CONSTRUCTION OF LOOSE-COUPLER

The figures are in the main self-explanatory. They should be studied in connection with those shown on the opposite page. The manner of winding; of taking taps; adjusting sliding contact, etc., are clearly shown.

spacing depending upon the kind of contacts which are to be used.

The movable base L is a square piece of dry wood 4 inches long, 4 inches wide and about ¾ inch thick. Care should be taken to have the edges of this block cut square with respect to the sides.

The panel M should now be screwed to the movable base L, as shown in Fig. 1. Care should be taken to have the edges of the blocks M and L evenly lined up so that the two edges of the block L (Fig. 1) which slide along the inside edges of the strips H and I will be smooth continuous surfaces.

*Fixed Coil Tube and Panel (P and K, Fig. 1).*—The coil tube P (Fig. 1) is essentially the same as the tuner described in Circular 120, and the tuner used there may be made a part of P of this set. The cardboard cover should be glued to the end of the tube where the single turn taps are taken off. This tube is 4⅛ inches in diameter and 4 inches long.

If a new coil tube is constructed, it may be improved by using a somewhat different arrangement of the twisted taps. See coil marked "Tuning Coil" in Fig. 3, Circular 120. Instead of taking off taps in a line from the upper right-hand corner to the lower left corner of the figure, start at the upper left corner and progress downward to the lower right corner.

The end of the coil tube where the 10-turn taps are taken off should have the cardboard cover glued to it. This is the top of the coil tube as it is shown in the diagram (Fig. 3, Circular 120). In all other respects the tube is wound exactly as described in Circular 120.

The panel which was described in Circular 120 may also be used for the panel K (Fig. 1). If the receiving set described in Circular 120 has not been constructed, this panel may be made from a board 7½ inches long by 4½ inches wide and about ½ inch thick. The position of the contacts can best be determined by inserting the switch arms in their respective holes and turning the knobs so that the ends of the switch arms will describe arcs, as previously explained. The contacts, and switch arms and knobs are described in Circular 120.

*Fixed Base and Coil Tube Support (B and J, Fig. 1).*—The fixed base B is a piece of dry wood 5½ inches wide, 11 inches long and between ¾ and ⅞ inches thick. The support J for the fixed coil tube is 5½ inches wide (the width of the base), 6 inches long and about ½ inch thick. This board should be screwed to one end of the base so that it is held securely in a vertical position. It will then project about 5 inches above the base G.

A strip of wood I, 11 inches long, 5/16 inch wide and about ¼ inch thick is now fastened to the base by cigar box nails or small brads so that it is even with the rear edge, as shown in the drawing (Fig. 1). The upright panel M having been fastened to the movable base L, as previously explained, is placed in position as shown.

The next step is to locate the strip H in such a position that the block L will slide easily back and forth the entire length of the fixed base B. Having found this position this strip is secure in the same manner as the strip I.

It is, of course, understood that neither the movable coil tube S nor the switch contacts and binding posts have, up to the present time, been mounted on the upright panel M. The wooden parts for the loose-coupler are now finished and should be covered with paraffin according to instructions given under *"Accessories."*

It might be advisable after winding the tube coils P and S to dip them in hot paraffin. This will help to exclude the moisture. It is important to have the paraffin heated until it just begins to smoke, as previously explained, so that when the coils are removed they will have only a very thin coating of paraffin.

### VARIABLE CONDENSER AND CRYSTAL DETECTOR

*Variable Condenser (C, Figs. 1 and 2).*—The variable air condenser should have a maximum capacity of between 0.0005 microfarads (400 to 400 micromicrofarads). The type pictured in Fig. 1 is inclosed in a round metal case, but the "unmounted" type may also be used. A person adept with the use of tools can make the variable

air condenser, but a discussion of the method is not within the scope of this pamphlet.

The variable condenser is mounted on a board R (Fig. 1) about 10 inches long, 5½ inches wide and ¾ inch thick. This board is similar to the baseboard used for the set described in Circular 120. The strips of wood are fastened under the ends so that wires may be run underneath for connections. After the holes for the detector binding post, and also the holes for the telephone binding posts U have been drilled, the board should be coated with paraffin, as previously described.

*Crystal Detector (D, Figs 1 and 2).*—The galena crystal may be mounted as described in Circular 120, or it may be mounted as pictured in Figs. 1 and 2. The holder for the crystal is a metallic pinch-clip such as the ordinary battery test clip or paper clip. This clip should be bent into a convenient shape so that it may be fastened to the base.

The wire X which makes contact with the crystal is a piece of fine wire (about No. 30) which is wound into the form of a spring and attached to a heavy piece of copper wire (about No. 14). This heavy wire is bent twice at right angles, passes through the binding post, and has a wood knob or cork fixed to its end as shown. It is desirable to have the fine wire of springy material such as German silver, but copper wire may be used if necessary.

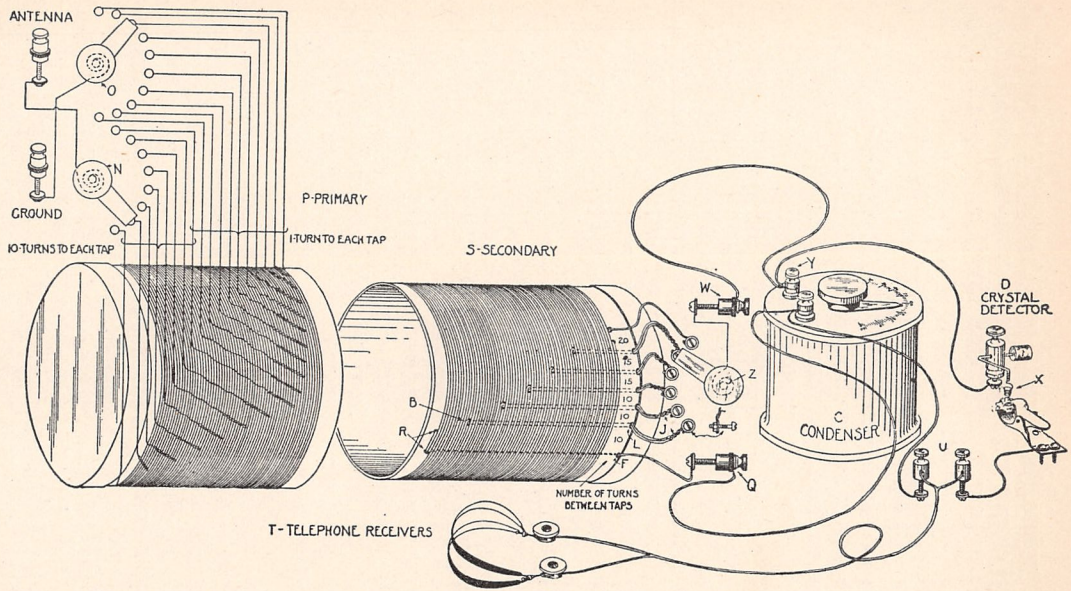
The importance of securing a tested galena crystal can not be emphasized too strongly, and it should be understood that good results cannot be obtained by using an insensitive crystal.

### INSTRUCTIONS FOR ASSEMBLING AND WIRING

*Coupler.*—The movable portion of the coupler should be assembled first. As shown in Fig. 1, the fittings making up this part of the set are the movable base L, the coil tube support M and the coil tube S.

Insert in M the 6 switch contacts (machine screws), the switch arm, and the binding posts, in the proper holes which have been drilled.

Adjust the switch arm until it presses firmly on the




SEMI-DIAGRAMMATIC PRESENTATION OF THE LOOSE-COUPLER SET, WITH VARIABLE CONDENSER

The ways in which both primary and secondary coils are tapped are clearly shown, and the picture constitutes, in effect, an elaborated hook-up, all the connections being indicated or depicted.

contact points (bolt-heads) and fasten the bare end of a No. 24 copper wire between the nuts on the end of the switch-arm bolts 2 (Figs. 1 and 2) which project through the panel M. Wind this wire into the form of a spiral of two or three turns like a clock-spring, leaving a few inches of the wire for connection.

Insert two small screws V (Fig. 1) in the panel M so that the switch arms will not drop off the row of contact points when the knob is turned too far.

The coil tube is now ready to be fastened in position on the panel M. Cut a 1-inch hole in the cardboard end of the coil tube and place it with the closed end next to the panel M in such a position that it will be just below the row of nuts and washers (switch contacts) and in the center of the panel M with respect to the sides. Fasten it to the panel with short wood screws.

The switch-arm bolt with the spiral wire connected to it should project through the hole cut in the end of the coil tube. Thread the end of this wire through a hole punched near the end of the coil tube next to the panel and connect this wire to the back of the binding post W (Figs. 1 and 2). The wire F (Fig. 2) is now connected to the back of the binding post Q.

There now remain 5 twisted taps and 1 wire to be connected to the 6 switch contacts. The taps should be cut off about 1½ inches from the coil tube and the insulation removed from the pair of wires thus formed. Each pair of wires should be twisted together, as shown at J, Fig. 2.

The connections are now made by clamping the 5 taps and also the end of the single wire between the nuts and washers on the contact bolts. The connections are clearly shown in the diagram.

We are now ready to assemble and wire the fixed portion of the coupler, composed of the base B, coil support J, panel K and coil tube P. As previously mentioned, the panel K is practically the same as the panel shown in Circular 120 except that for this purpose the original panel is mounted so that the lower edge now becomes the left-hand edge. This brings the series of 10 contacts at the top of the panel in our present set. When the panel

is turned to this position the two binding posts will be at the top. Change the position of the right-hand binding post so that the two switch arms are made as described in Circular 120.

Two short pieces of wire should now be fastened under the binding posts at the front of the panel. These wires are arranged so that there is a very short space between their ends, as explained in Circular 120. Screw the panel K to the base B and to the support J, meanwhile allowing the coil tube P to lie on the base so that the connecting wires will not be broken.

If the panel has been made especially for this coupler, as described in this pamphlet, it should be mounted according to the following instructions.

Screw the panel to the base and to the support J and insert the binding posts, switch arms and bolts, and contact bolts in the proper holes. The switch arms should now be adjusted so that they make firm contact on the heads of the bolts. Now insert 4 small screws (E, Fig. 1) in the front of the panel so that the switch arms will not drop off the row of contact points when the knobs are turned too far. Insert a wire between the nuts on the end of the lower switch-arm bolt N where it projects through the back of the panel K (Fig. 1). Wind the wire into a spiral of 1 or 2 turns like a clock-spring and connect the end to the upper binding post which is marked "antenna."

These connections will be understood by referring to the upper left-hand corner of Fig. 2.

In the same manner connect another wire from the upper switch-arm bolt to the lower binding post which is marked "Ground." (See Fig. 2.) The connecting wires should be insulated except where a connection is needed and should not touch each other. Two short pieces of wire are now fastened to the binding posts in the front of the panel, as previously explained.

The coil tube P should now be laid on the base in about the same position as it is shown in Fig. 1. The 16 twisted taps and also the 2 single wires from the ends of the winding are now to be connected to the back of the 18 contacts on panel K, following the method given in Cir-

cular 120. The order of connecting the taps may be understood by referring to Fig. 2.

The following instructions will apply whether the coil tube P was made according to the description in Circular 120, or was made according to instructions given in this pamphlet.

Carefully raise the coil tube P against the support J to such a position that when the coil tube S of the movable section of the tuner is pushed in the coil tube P, the space between the two tubes will be equal all around. Mark this position of the coil tube P on J, and fasten it to J with short wood screws.

*Condenser and Crystal Detector (C and D, Fig. 1).*— The mounting of the condenser C and the crystal detector D on the base R is clearly shown in Fig. 1. Crystal detectors have been previously described in this pamphlet and in Circular 120. A wire is run from the binding post Y on the variable condenser C, through a small hole in the base R, and is then connected to the under side of the detector binding post.

Another wire is now run from the clip which holds the galena crystal, through a small hole in the base, and is then connected to the under side of the right-hand binding post U. The left-hand binding post U is next connected to the binding post on the variable condenser which has no wire attached to it, by running a wire under the base and up through a small hole.

The wiring will be understood by referring to the right-hand portion of Fig. 2. The wires may be the same size as were used for winding the coil tubes and should be insulated. Two pieces of wire should now be connected from the binding posts W and Q (Figs. 1 and 2) to binding posts on the variable condenser.

The telephone receivers T are now connected to the binding posts U and the receiving set is complete except for connecting antenna and ground.

The connection of the antenna lead and ground wire to the binding posts marked "Antenna" and "Ground" respectively is made as shown in Fig. 2 in Circular 120.

The coil tube P is usually called the "primary" and the coil tube S is usually called the "secondary."

DIRECTIONS FOR OPERATING

Push the coil tube S (secondary) about half way into the coil tube P (primary) and set the switch 2 on contact point 4. The primary switch N is set on contact 8. The primary switch O may be left in any position. The crystal detector can be adjusted most easily by the use of the test buzzer, which is described below.

If the test buzzer is not used the wire which rests on the crystal must be placed lightly at different points on the crystal until the transmitting station is heard when the set is adjusted as described below.

Having adjusted the crystal detector to a sensitive point, the next thing is to adjust the switches on the coil tube P (Primary), the switch on the coil tube S (secondary) and also the variable condenser C so that the apparatus will be in "resonance" with the transmitting station.

Set the primary switch N on contact point 1 and while keeping it in this position move the other primary switch O over all of its contacts, stopping a moment at each one.

Care should be taken to see that the ends of the switch arms are not allowed to rest so that they will touch more than one contact point at a time.

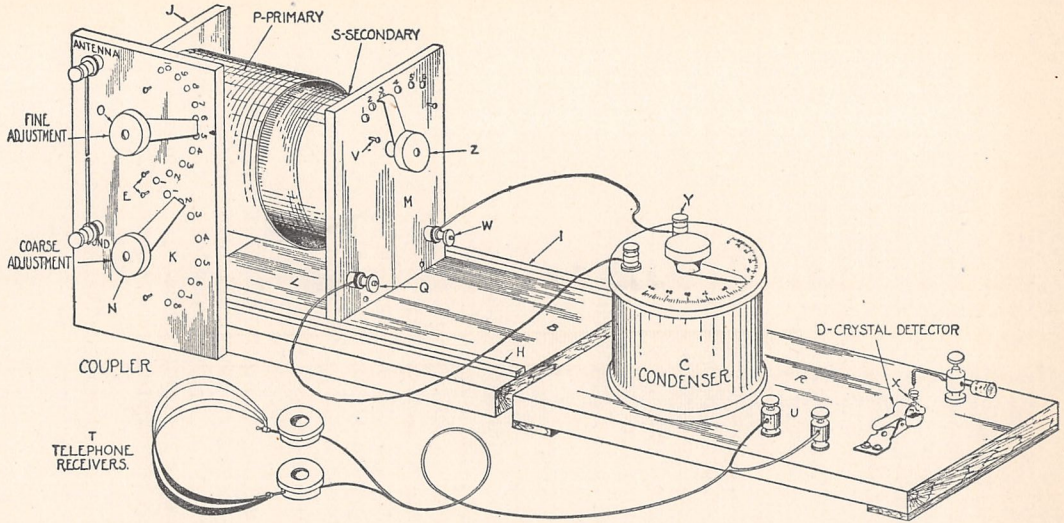
If no signals are heard, set the switch arm N on contact point 2 and again move the switch arm O over all of its contents. Proceed in this manner until the transmitting station is heard. This is called "tuning" the primary circuit.

The tuning of the secondary circuit is the next operation. Set the secondary switch Z on contact point 1 and turn the knob of the variable condenser C so that the pointer moves over the entire scale.

If no signals are heard, set the switch 2 on contact point 2 and again turn the knob of the variable condenser so that the pointer moves over the entire scale.

Proceed in this manner until the signals are loudest, being careful to see that the ends of the switch arms touch only one contact point at a time.

Next slide the coil tube S (secondary) in and out of the coil tube P (primary) until the signals are made as loud




THE LOOSE-COUPLER RECEIVING SET READY FOR OPERATION

This is a more pictorial presentation of the loose-coupler set already shown. The set is now ready for operation. As the inductive influence may be modified by sliding the secondary in and out of the primary, and as the current may be further modified by taps on both primary and secondary, there is opportunity for selective tuning; which may be further modified with the aid of the variable condenser. The crystal detector is seen, simply mounted, at the right.

as possible. This operation is called changing the "coupling." When the coupling which gives the loudest signal has been secured, it may be necessary to readjust slightly the position of the switch arm O, the position of the movable coil tube S and the "setting" of the variable condenser C.

The receiving set is now in resonance with the transmitting station. It is possible to change the position of one or more of the switch arms, the position of the movable coil tube and the setting of the variable condenser in such a manner that the set will still be in resonance with the same transmitting station. In other words, there are different combinations of adjustments which will tune the set so that it will respond to signals from the same transmitting station.

The best adjustment is that which reduces the signals from undesired stations to a minimum and still permits the desired transmitting station to be heard. This is accomplished by decreasing the coupling (drawing coil tube S farther out of coil tube P) and again tuning with the switch arm O and the variable condenser C. This may also weaken the signals from the desired transmitting station but it will weaken the signals from the undesired station to a greater extent, provided that the transmitting station which it is desired to hear has a wave frequency which is not exactly the same as that of the other stations. This feature is called "selectivity."

*The Test Buzzer.*—As mentioned above, it is easy to find the more sensitive spots on the crystal by using a test buzzer. This has been described in Circular 120 and is shown at Z, Fig. 3, in that publication. [See Chapter III, page 73, of this book.] Referring to this figure, the binding post marked "ground" should be connected by a flexible wire to the binding post W, which is shown in Fig. 1 in this pamphlet. The operation of the test buzzer has been described in Circular 120.

## APPROXIMATE COST OF PARTS

The following parts are used in the equipment described in Circular 120 and are needed also for the two-circuit set described in this pamphlet.

| | | |
|---|---|---|
| Antenna: | | |
| Wire—copper, bare or insulated No. 14 or 16, 100 to 150 ft., about<br>Rope—¼ or ⅜ inch, 2c. per foot. | $0.75 | |
| 2 Insulators—porcelain | 0.20 | |
| 1 Pulley | 0.15 | |
| Lightning Switch — 30-ampere battery switch | 0.30 | |
| 1 Porcelain Tube | 0.10 | |
| Ground Connections: | | |
| Wire (same kind as antenna wire). | | |
| 2 Clamps | 0.30 | |
| 1 Iron Pipe or Rod | 0.25 | |
| Receiving Set: | | |
| 3 Ounces No. 24 double cotton covered copper wire | 0.40 | |
| 1 Round Cardboard Box.<br>2 Switch Knobs and blades, complete | 1.00 | |
| 18 Switch Contacts and nuts | 0.75 | |
| 3 Binding Posts—set-screw type | 0.45 | |
| 2 Binding Posts—any type | 0.30 | |
| 1 Crystal—tested | 0.25 | |
| 3 Wood Screws—brass, ¾ inch long | 0.03 | |
| 2 Wood Screws for fastening panel to base. | 0.02 | |
| Wood for panels (from packing box). | | |
| 2 Pounds Paraffin | 0.30 | |
| Lamp Cord—2 to 3 c. per foot. | | |
| Test Buzzer | 0.50 | |
| Dry Battery | 0.30 | |
| Telephone Receivers | 4.00 to | 8.00 |
| Total | $10.35 to | $14.35 |

The following additional parts will be required:

| | | |
|---|---|---|
| 3 Ounces No. 24 double cotton covered copper wire | $0.40 | |
| 1 Round Cardboard Box.<br>1 Switch Knob and blade, complete | 0.50 | |
| 6 Switch Contacts and nuts | 0.25 | |
| 2 Binding Posts—any type | 0.30 | |
| 1 Battery Clip for crystal | 0.10 | |
| Miscellaneous Screws | 0.30 | |
| 1 Variable Condenser—0.0004 to 0.0005 microfarads (400 to 500 micromicrofarads) | 3.00 to | 6.00 |
| Total additional cost | $4.85 to | $7.85 |

## CHAPTER V

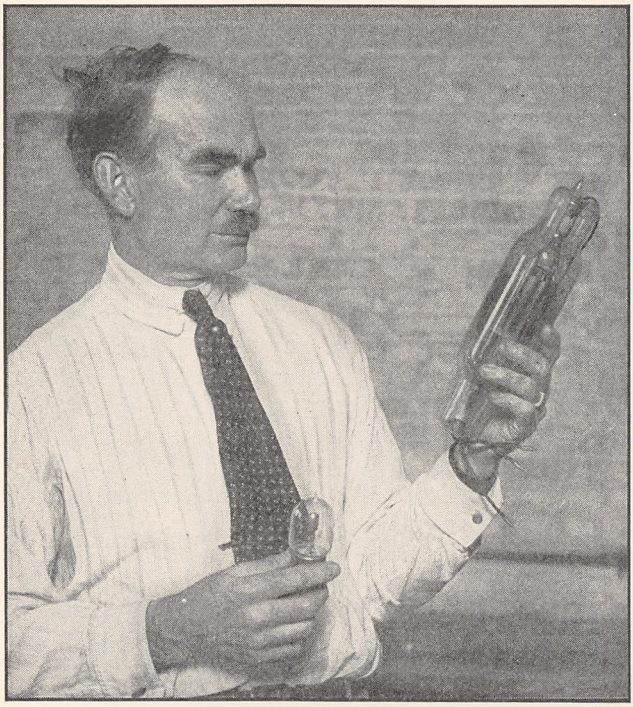
## FROM CRYSTAL TO TRIODE

ONE want supplied another springs. When we have brought the tuning mechanism to a higher plane of efficiency, it is a moral certainty that we shall soon cease to be content with our crystal detector. However well it may work in "detecting" messages from nearby stations, and however carefully we may adjust the "cat whisker" to find the most sensitive axis, the crystal has inherent limitations as to sensitiveness. It cannot interpret messages coming from stations that, in the modern radio sense, are very distant. Ordinarily its range is limited to twenty or twenty-five miles; subject of course to variation with the power of the transmitting station.

That will not do at all for the amateur who is beginning to think himself no longer a novice. And so, as we have taken the trouble to improve the tuning apparatus, thus putting ourselves in position to select messages of different wave-lengths, we must now seek the aid of a more sensitive detector in order to reap the full reward of our efforts.

This means that we must take out the crystal detector and put in its place a detector of totally different type—a little apparatus that has been already more than once referred to and which will ultimately claim a large share of our attention, but which for the moment we may be content merely to introduce as the audion, so named by its inventor, Dr. Lee DeForest; otherwise known as vacuum-tube, three-electrode vacuum tube, electron tube, ionic valve, thermionic valve, and—perhaps best of all—triode.

It is this necromantic tube that we are to examine somewhat in detail in the present chapter. And in speaking thus I use the word "necromantic" advisedly. In the



DR. LEE DE FOREST

Who put the "grid" in the electron tube, and thus invented the wonder-working audion, or triode. The tube in his right hand is of usual size; that in the left hand is a large "power" tube, used in transmitting.

entire range of applied science there is perhaps no other mechanism that surpasses the audion tube in capacity for weirdly mystifying activities. The capacity to rectify alternating currents and thus serve the purpose of

a detector in the receiving telephone mechanism is but one of these, as we shall see.

It is, however, as the most sensitive of detectors that the vacuum tube will first claim our attention. We shall learn that the strange little mechanism can not only detect the most infinitesimal of currents (Dr. Lee DeForest himself has expressed the opinion that there is no lower limit to its sensitiveness), but that it can also amplify the current, magnifying it almost beyond belief—in effect accentuating a whisper until it becomes a shout. The single audion tube is usually not called on to do this, to be sure; but other tubes may be linked with it, each new one taking up the work where the last one left off, so that it is almost as difficult to mark the upper limit as the lower limit of its activities.

When President Harding's inaugural address is heard blocks away better than by those who are standing within a stone's throw of the platform where he speaks; or when the Secretary of the Navy delivers a speech aboard a ship out in the North River and crowds at Times Square, New York, listen to it—the vacuum tube is to be credited, for it alone makes such things possible.

### HEARING WITH AN ELECTRIC LIGHT

Some one with a feeling for the picturesque use of words has referred to the use of the audion as "hearing with an electric light." It is almost literally that, for the audion tube is an electric light—let us say, an electric light, *plus*.

Of course if you wish to be quite literal, you may assert that the hearing is done with our ears, and that it is the diaphragm of the telephone receiver that oscillates to produce the audible sound waves; but back of the telephone receiver is the electric current coming from the audibon tube, and without that current, ade-

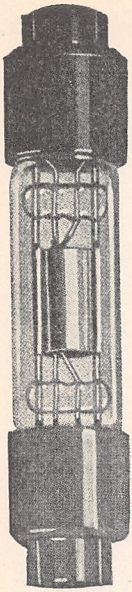


Fig. 1.

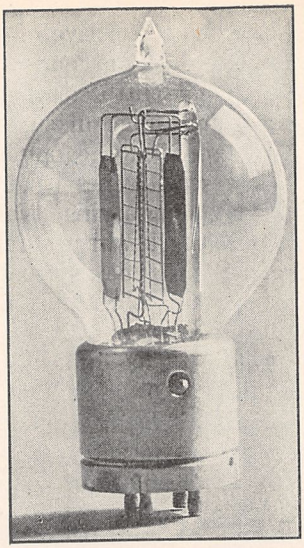
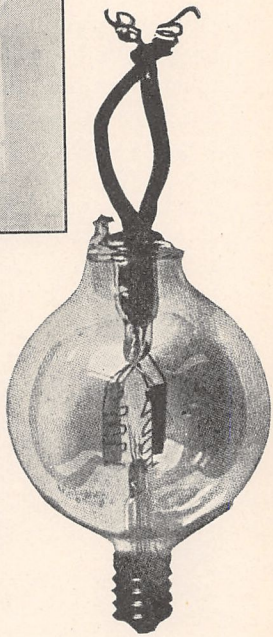


Fig. 2.

VARIOUS TYPES OF TRIODES

Figure 1. Myers Tube, a departure from the conventional shape.
Figure 2. A tube with the plate in two parallel parts, with divided grid.



AN EARLY TYPE OF DE FOREST AUDION, and the SYMBOL FOR AUDIONS, or TRIODES, OF ANY TYPE

quately amplified, the diaphragm of the telephone receiver would be only so much inert metal.

It is the all-essential work of the audion as detector and amplifier that makes the radio receiver the amazing thing that it is. The crystal detector is wonderful enough—there is no reason to disparage it. But it has marked limitations. There is a conspicuous limit to its sensitiveness. The radio current must have a certain measure of intensity far above the audion tube's lower limit of practical efficiency, in order to affect the crystal appreciably; and under no circumstances is the crystal able to amplify the current. Other mechanisms used in connection with the crystal may do something in that direction, but at best they are futile competitors of the series of audion tubes.

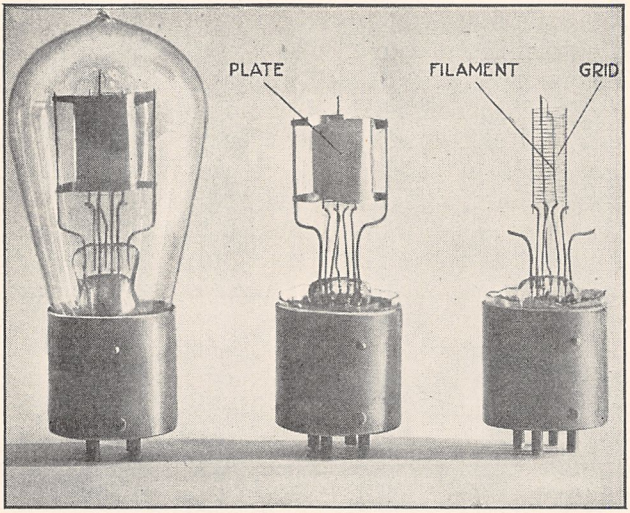
And that is equivalent to saying over and over again that the audion tube is the detector par excellence—the incomparable wonder-worker.

To tell of the achievements of the little vacuum tube, is to use words that smack of fantasy, of the downright miraculous—almost of the unbelievable. Something of mystery there is, in any event, about all electrical phenomena. Yet fortunately it happens that the modern scientist has been able to develop a theory of electrical action that has the merit of tangibility; and this theory, applied to the audion tube, enables us to gain a very definite notion of the way in which the little wonder-worker operates. We can form a concrete image of its manner of action, and in imagination can see the flight of electrons that is the essential feature of all that the tube accomplishes.

A page or two back we spoke of the audion tube as an electric light *plus*. That is an accurate characterization, but obviously calls for interpretation. Fundamentally, then, we have an electric light bulb, with a tungsten filament, heated to incandescence, when the tube is in operation, by an electric current usually sup-

plied by a storage battery, usually referred to as the "A" battery.

So far, the electric light. The *plus* part consists of two highly important additional factors: (1) a metal plate or cylinder at a distance from or surrounding the filament; and (2) between the plate and the filament




THE COMPONENTS OF THE TRIODE

At the left, the completed tube, in which the tubular plate hides the grid and filament, which are revealed in the dissection at the right.

a coil of wire or a perforated plate or cylinder known as the grid.

### COMPONENTS OF THE TRIODE

The three devices within the electric light bulb, then, are the tungsten filament, centrally located, the plate, well removed from the filament; and the grid between the two. Whatever the shape of plate and grid, this

arrangement is the conventional one, and only departed from in experimental tubes of exceptional construction that do not concern us here. The plate is connected with the positive pole of an auxiliary battery, usually spoken of as the "B" battery. Exceptionally there may be a "C" battery, actuating the grid-filament circuit.

What happens within the tube when in action is to be thought of in terms of that ultimate electrical agent, the electron. It is known that when a metal body is heated, a vast number of electrons fly out from its surface. This happens in the ordinary electric light bulb; but under ordinary conditions most of the electrons are quickly drawn back again to the filament; partly because the atoms that have lost electrons become thereby positively charged and so attract the negatively charged electrons that are tending to escape; and partly because the electrons that first escape tend to repel the ones that come after them (similarly charged bodies always repel one another, of course), and so drive them back.

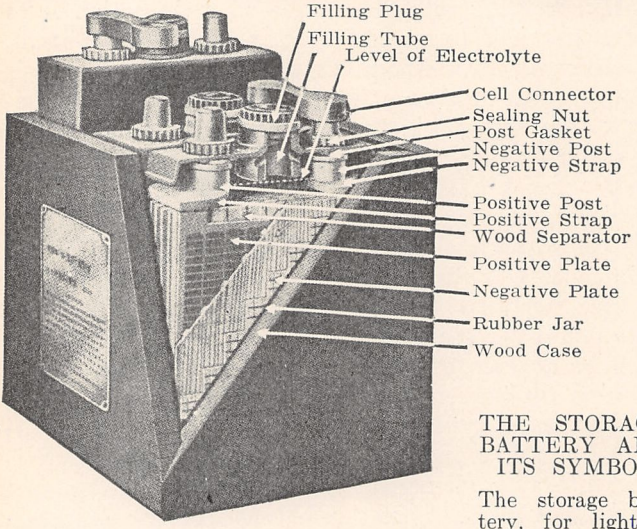
But in the audion tube, with its additional elements, the grid and the plate, conditions are obviously modified. Both grid and plate are electrified, and each is there to play a significant rôle in determining the fate of the electrons that are thrown out from the luminous filament.

Let us here suppose that the electron tube is introduced into the electrical circuit of the receiving telephone, in place of a crystal, to serve as detector. Then the incoming wire, bringing the alternating current from the aerial by way of tuning apparatus and condenser, is connected directly with the grid. The filament, as we have seen, is heated by an auxiliary battery ("A"); and the plate is also connected with an independent auxiliary battery ("B"). The function of the filament battery is to heat the filament and thus cause it to discharge electrons. The function of the battery connected with the plate is to keep the plate positively

charged so that it will attract the negatively charged electrons.

The current that comes to the grid is, then, the high-frequency alternating current, exceedingly feeble at best, representing the radio message.

If we attempt to visualize this current, we must think




THE STORAGE BATTERY AND ITS SYMBOL

The storage battery, for lighting the filament, is almost universally referred to as the "A" battery.

of it as a surge of electrons along the conducting medium first in one direction and then in the other. It is not supposed that individual electrons travel great distances. The apparent flow of current is the aggregate result of movement through short distances of large numbers of electrons.

And the net movement of the electrons, in the case of any current of electricity, is from the negative toward

the positive pole,—just reversing the idea of the earlier students of electricity, who thought of the current as flowing always from the positive to the negative.

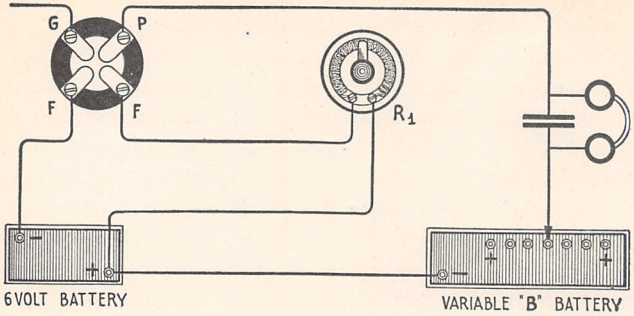
The difference of voltage, or electromagnetic force, between the two poles, or electrodes, which determines the electron-flow, is spoken of as "potential." "Positive potential" and "negative potential" are relative terms expressing a mutual relation, like higher and lower levels of altitude. We say that one electrode has, for example, a three-volt positive potential, or that the other electrode has a three-volt negative potential,—the two statements being equivalent.

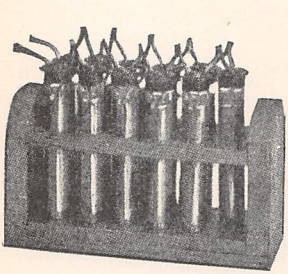
Just as you might say that one weight is three pounds heavier or a second weight three pounds lighter.

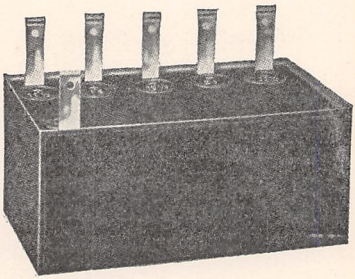
If, now, in the circuit just imagined, in which there is a three-volt difference of potential, a negative potential of two volts is impressed on the positive electrode (as by a battery), this electrode will still be positive, but only by a potential of one volt. One more negative volt impressed will make the circuit neutral, or of even potential. And any further impression of negative voltage will make the erstwhile positive electrode negative; the former negative's electrode automatically becoming positive.

Such alternations of potential between two electrodes in a circuit will take place if an alternating current is impressed on that circuit—as when a radio message comes to the radio-receiving apparatus. The strength of the input current will determine whether the electrodes of the receiving circuit will actually change places (from positive to negative and the reverse) with each oscillation; or whether the neutral point will merely be approached,—the difference minimized, but the polarity not reversed.

If, for example, to hold to the illustration just suggested, there is a difference of potential of three volts in the electrodes of the receiving circuit, the input alter-

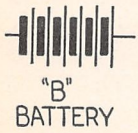




## THE "B" BATTERY AND ITS SYMBOL

Usually a dry-cell battery as in the lower figure, at the left. A storage "B" battery, as in lower figure at right, is gaining in popularity because it can be recharged.




The upper figure shows a hook-up for a simple installation of triode detector (*G*, the grid lead; *P*, the plate lead; *F* and *F*, the filament leads), with Rheostat (*R*) to control filament (6-volt "A" battery) current.

nating current must be of more than three-volt strength in order to change the positive electrode to negative and vice versa. A two-volt input current, for example, would merely make the positive electrode shift between one volt (3 minus 2) positive and five volt (3 plus 2) positive; the negative electrode of course undergoing reciprocal alternations.

Meantime the positive electrode in the circuit under consideration, even at its five-volt maximum potential, may be negative as regards an electrode of a second circuit (having, let us say, a six-volt potential); and the negative electrode of our first circuit may be positive with regard to a third circuit having a half-volt potential.

In a word, all voltage relations are relative, and subject to indefinite permutations.

I stress these elementary facts because they must be clearly in mind if we are to understand the action of the electron tube.

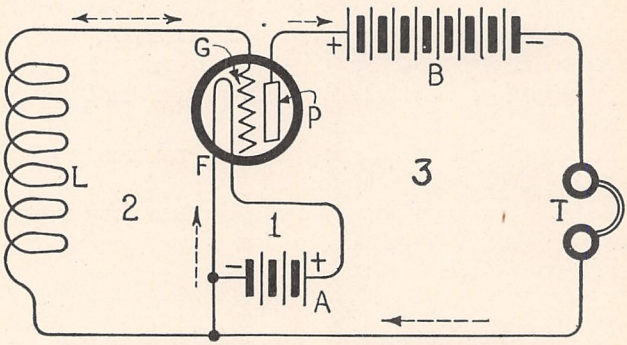
### FLOW OF ELECTRONS THROUGH THE TRIODE

The circuit in which the alternating current bearing the radio message flows to the electron tube is called the grid-filament circuit. Under normal adjustment, there is little difference of potential between grid and filament, but the grid potential tends to shift incessantly from positive to negative with the oscillations of the input current. Meantime the plate is always of positive potential with regard to the filament, with which it also is in circuit. But there is a larger circuit that involves plate and grid (taking in plate battery, telephones, and tuning coil), and it is comprehensible that there might be an actual flow of electrons from grid to plate.

The quantity of such flow of electrons from grid to plate, however, would be negligible (if it occurs at all) in comparison with the relatively enormous flow from

the heated filament to the plate. But the flow of this major stream of electrons must be influenced very markedly by the changing potential of the grid. When the grid is positive (as regards the filament), it will facilitate discharge of electrons from the filament; and these electrons, bombarding the grid, or shooting through its interstices, constitute a current flowing to the plate.

It must be recalled that the grid, although now positive as regards the filament, will still be negative as




SIMPLE TRIODE-DETECTOR HOOK-UP

The numerals indicate the three circuits. The double-headed arrow indicates alternating input current; the single-headed arrows, the rectified output current.

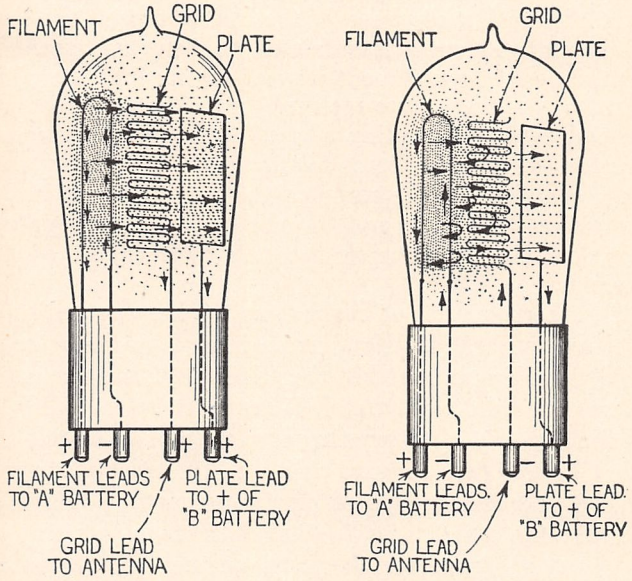
regards the plate, and so may doubly facilitate the flow of electrons. Electrons, it must be recalled, are all of one tribe, no matter what their origin; so there is no distinction between those that come to the grid from the aerial and those that come from the filament. The two groups may coalesce and pass across the vacuum space to the plate, and then along the plate wire to the telephone receivers, as components of the same current.

Thus the current that leaves the triode, via the plate, is greatly amplified or accentuated as compared with the current that enters via the grid. A measure of ampli-

fication is therefore inherent in the action of the electron-tube.

### THE GRID CONTROLS THE PLATE CURRENT

But now we must recall that with each alternation of phase of the input current, the grid changes its potential, and becomes negative (or at any rate less positive) as




THE FLOW OF ELECTRONS IN THE TRIODE

At the left, active flow of electrons from filament to plate when the grid is positive. At the right, the flow of electrons checked by the negative grid, rectifying the current.

regards the filament. Now instead of facilitating it will tend to retard the flow of electrons from the filament. Electrons cannot flow from cold grid to hot filament; but, repelled by the negative grid, many electrons will be driven back into the filament. Doubtless the flow

from filament to plate will not be altogether interrupted, owing to the relative power of the current in the plate-filament circuit; but it will be conspicuously retarded.

In other words, the output current, passing from the plate to the telephones, will be much less energetic when the grid is of strongly negative potential than when it is less strongly negative, or slightly positive.

But this is obviously equivalent to saying that with each alternation of phase of the input current, the flow of the output current is restricted; and this statement in turn, is only a roundabout way of saying that the plate current is in a measure rectified, or made into a pulsing instead of an alternating current. A two-way current, bearing the message, came to the triode; a one-way current, carrying on the message to the telephone, leaves the triode. And the grid, thanks to its varying potential, has been responsible for this rectification of the current.

Such rectification of current, as we know, constitutes the function of "detection" as performed by the detector crystal. Now we see that the triode performs the same function. Like the crystal, it tends to reject half the oscillations of the alternating current, and to permit the other half to pass forward as a direct current pulsing in unison with the groups of electro-magnetic waves that came to the aerial from the distant transmitting station.

We may ignore for the moment the fact that such rectification is never complete, but only relative; and the further fact that, in case of the triode, varying degrees of modification may be produced at will by modifying the relative voltages of grid and filament (with a "C" battery or with a voltage-divider, often called "potentiometer"). Suffice it for the moment that the analysis just given presents at least a general view of the way in which the triode acts as detector, modifying the input current from the alternating condition in which it could

not affect the telephone diaphragms to the direct or pulsing current that can affect them.

Meantime we have seen that, thanks to the local batteries which make the filament incandescent and keep the plate at high positive potential, there is accentuation or amplification of current, so that the triode in effect acts as a relay.

We shall have occasion later to see how the current can be so manipulated that maximum amplifying qualities are brought out. We shall learn that special amplifying tubes, differing from the detectors chiefly in that that they are of a higher vacuum, are employed on occasion. But we already know why it is that even the simple detector tube, such as we are about to install in our receiving telephone system, amplifies the current, even as it rectifies it. This is one of the super-functions of the audion tube which places that little instrument in a class apart, putting the crystal detector entirely out of competition.

It has been noted that the audion tube has other important uses. Its capacity to act as oscillator, in sending wireless messages, will claim our attention presently. We shall have occasion also to observe the effect of joining audion tubes together "in cascade" as it is called, amplifying waves of radio frequency in one series and of audio frequency in another series with the aid of local batteries and transformers. But let it suffice for the moment to have presented the extraordinary little electric light bulb *plus* in the simple rôle of detector (always with an element of amplification) in the circuit of our radiophone receiver.

### INSTALLING THE TRIODE DETECTOR

It goes without saying that the detector-tube which is to replace the crystal detector in our improved radio receiving outfit must be purchased. Few amateur ex-

perimenters would think of trying to make an electric light bulb of the simplest kind, let alone the three-electrode bulb.

It goes without saying, also, that the cost of the triode is relatively large in comparison with the cost of a crystal detector. The latter, as we know, may be purchased for the fraction of a dollar; a good triode costs at best about $5.00.

And that is not all. The electron tube, as we are already aware, cannot be operated without the aid of a local electrical supply. The crystal-detector outfit, even when fortified with loose couplers and condensers, called for no local electrical equipment whatsoever,—not even a dry cell. We did, to be sure, use a dry cell with the buzzer in testing the crystal to find the most sensitive spots on its surface. But such tests had nothing to do with the actual receiving of radio messages except by way of preliminary, and not an indispensable preliminary at that. When the radio receiver was in actual operation, the buzzer and its dry cell were no longer in commission.

In a word, the radio-receiving outfit, with its crystal detector, as we have used it, has presented the really extraordinary phenomenon of an apparatus that receives its electrical supply solely by way of the electromagnetic waves in the ether from a transmitting station perhaps fifteen or twenty miles away. It developed an exceedingly feeble current of electricity, as might be expected under the circumstances; but nevertheless a current that sufficed, after being rectified by the crystal, to influence the magnetic field of the telephone head pieces sufficiently to produce audible sounds. Otherwise we could not have been listening to lectures and concerts from the broadcasting station.

But the magic electron tube, if merely wired into the detector circuit of the radio-receiver in place of the crystal, could by no means do the work that the crystal

has been doing. In fact, it would not work at all. Our outfit would be put quite out of commission.

A moment's reflection will tell us why. Indeed, the thing is too obvious to call for reflection. No one would expect an electric light to work by merely having wires attached to it. We attach the electric light bulb to a socket that brings an electric current from the power station; or we hook it up with a flashlight battery. The filament will become bright only when an electric current passes through it.

Obviously the same thing must apply to our triode, which is primarily an electric light. We must have an electric current, quite different in power from that which comes from the antenna, to bring its filament to incandescence.

The natural thing to do, one might suppose, would be to bring an ordinary electric light current into requisition. But we shall quickly be informed that this would not answer at all. The ordinary electric light current comes to us at 110 volts, pulsing 60 cycles per second. Such a voltage would be altogether out of proportion to the feeble current that will come to the grid of our little lamp from the aerial; and even if we were to use a step-down transformer and reduce the voltage, we should still have to deal with the 60-cycle pulsation, which is an audible frequency that would register itself as an overpowering humming sound that would drown out the message for which we are listening.

Parenthetically, it may be said that the difficulty can be overcome. On the very day when these lines are being written, word comes from Washington that the experts of the Bureau of Standards have been wrestling with this problem and have found a way to utilize ordinary electric light current to actuate the triode, or series of triodes, in the radio receiving telephone outfit. We shall later have occasion to examine the new and interesting method in detail, and we may well believe that the or-

dinary electric light current will presently be available for operation of the triode detector and amplifier. The Bureau of Standards method, however, involves the use of several radio-frequency amplifying tubes; a crystal detector to supplement these; and additional tubes for audio-frequency amplification.

At the moment, we are not prepared to deal with so complicated an apparatus as that. Our present concern is with a single detector triode, and as we now introduce this, as substitute for the crystal we have hitherto used, we have no resource but to adopt the conventional usage, providing ourselves not merely with a local battery, to bring the filament to incandescence; but also with a second battery to connect with the plate of the little tube. The grid will receive its current, directly or indirectly, from the aerial, bringing the all-important radio messages.

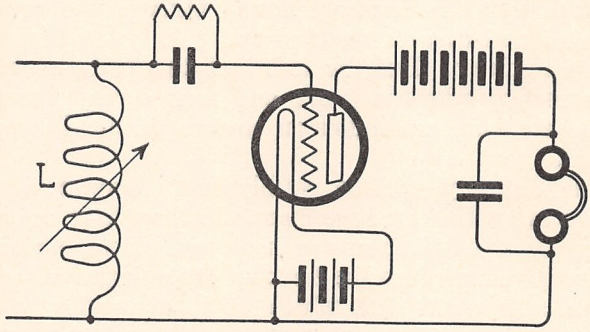
Somewhat recently a particular type of triode has been put on the market which is operated by a single dry cell. This is a hopeful augury, and no one can say what the morrow may bring forth in the way of similar improvements. But as triodes in general are constructed at the moment, conventional usage calls for a storage battery of about 6 volts to actuate the filament. A conventional type of such battery is called a 40-ampere battery; the meaning being that this battery will give a one-ampere current for forty hours.

The storage battery required does not differ in principle of action from the one with which most owners of automobiles are familiar. It is heavy, expensive, and it must be recharged from time to time. If carelessly handled, it may leak sulphuric acid, with damaging effect to everything in its neighborhood.

In a word, the storage battery is an encumbrance that one would willingly dispense with. But the triode lamp must be lighted, or we shall not be able to listen to the concert from that distant broadcasting station; so we

accept the necessary evil, and turn attention, with such grace as we can command, to purchase of the second battery,—the one that is to actuate the plate circuit.

This second battery, fortunately, will not give us so much trouble. It is called a "B" battery, we learn, and half a dozen dry cells will supply the 22½ volts it is expected to furnish; with very low amperage, so that the life of the battery is long. It may be stored on a




TRIODE-DETECTOR HOOK-UP

The symbols for variable inductance, grid condenser and grid-leak, triode, batteries "A" and "B," and telephone (shunted by fixed condenser), will be readily recognized; and it is apparent that the diagram conveys very definite information from which any one, with a little practise, could install a radio-receiver with triode detector. Note that the positive lead of the "B" battery connects with the plate.

convenient shelf, as one stores the dry cells for a call bell, and very little attention need be paid it.

The storage battery for the filament (which we shall learn to speak of as the "A" battery) will require looking after from time to time. It must be kept supplied with distilled water, and occasionally recharged electrically. But for the moment, having the thing in hand, we are chiefly concerned to wire it up with the filament of our triode, and make whatever other connections may be necessary to link with the "B" battery circuit, and in

general constitute our amplified radio receiving apparatus a workable outfit.

### HOW TO MANAGE BATTERY WIRES

What we are planning to do, as is perfectly understood, is to introduce the electron tube in such a way that the current from the aerial (direct or induced) will flow through it, as it formerly flowed through the crystal detector and thus be rectified and pass on to the telephone receivers. But the fact that two batteries must be wired up with the triode and their current brought into the circuit, constitutes an obvious practical complication.

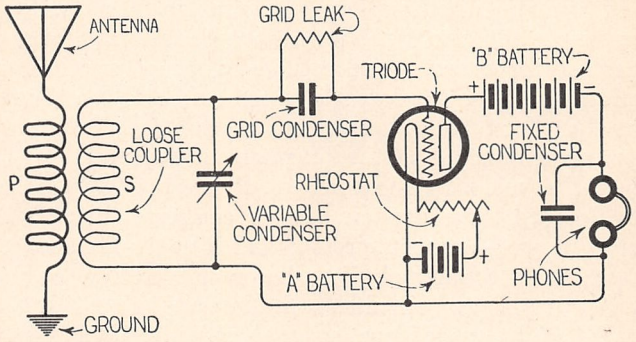
The difficulty will be readily met, however, if we glance at another of those plans which we have come to know as circuit diagrams or hook-ups. Here, for comparison, we reproduce the hook-up of the improved crystal-detector outfit with which we have previously operated, and which we are now taking to pieces in order that we may substitute the triode detector for the crystal.

Comparing this with the new hook-up (which represents our outfit as it will be when we have made the proposed change), we find that the left-hand part of the diagram, having to do with antenna system and loose coupler and variable condenser, is quite unaltered. The right-hand part of the diagram, where the telephone receivers are located, is also unchanged. The modification comes at the center of the picture, where what at first glance seems a rather complicated structure is introduced in place of the simple arrowhead and bar that represented the crystal in the other diagram.

This structure, however, is not really complicated if we simply analyze it. The pyramid and the spiral and the bar in the circle represent, as we know, the filament and grid and plate respectively of the triode. It will be seen that the wire coming directly from the secondary

coil, passes to the grid, which thus directly takes the place of the crystal. The introduction of a small fixed condenser between coil and grid need not confuse us; as we are already familiar with condensers, and can await further explanation as to just why this additional "grid condenser" is necessary; also as to why something designated a "grid lick" is associated with it.

If we follow the grid current back along the input wire, in the endeavor to see how the grid circuit is com-




ANOTHER SIMPLE TRIODE-DETECTOR HOOK-UP

Here we have a variable condenser shunted across the grid-filament circuit, and a rheostat introduced to control the filament current. The "A" battery is usually of six volts, and the "B" battery of 22½ volts for this single-tube outfit.

pleted (for we know that an electric current must travel in a circuit, coming back to the place from which it started), we find that, passing through the secondary coil and along the lower wire that leads from that toward the telephone headpiece, we come to a wire that goes to the negative lead of the filament circuit.

Focusing attention for a moment on these lines alone, we see clearly revealed a grid-filament circuit, across which there is shunted a variable condenser.

Well and good. We can readily connect the input wire with the grid of the triode; and can connect the

other wire leading from secondary coil to telephone headpiece with the wire that connects the negative of the storage battery with the filament.

And now it appears that nothing more is necessary but to insert the "B" battery with its positive lead attached to the plate-post of the triode and its negative lead linked with the negative lead of the filament battery; the telephone head piece being hooked into this circuit on one side or the other of the "B" battery.

In practise, nothing could be simpler than that; and when the thing is done, we have accomplished what the hook-up represents—the establishment of another new circuit with the triode plate at one end and the filament at the other (following around to the right in the diagram, and including the telephone headpiece).

Still considering the hook-up, it is clear that we have to do with three new circuits—a complete filament circuit; a grid-filament circuit; and a plate-filament circuit. It is equally obvious, however, that for the most part these new circuits coincide with or utilize the wired highways of our original radio receiving outfit. A greater or less extent of new wire has been used, as a matter of convenience, in connecting up the batteries. The wires from the "A" battery, feeding the filament, constitute a new departure altogether. They fulfil the function of lighting the lamp; but they also have an all-important association with the message-bearing current. The negative lead of this battery connects, as we have seen, with part of the old circuit; and the connecting wire serves as a joint highway for grid-filament and plate-filament circuits.

Of course we may wish to install the storage battery ("A") in the cellar, and the plate battery ("B") on a more or less distant shelf in the closet. Meantime our old outfit may be placed on a table at some distance from the window where the wire from the aerial enters and also at a distance from the water pipe where the

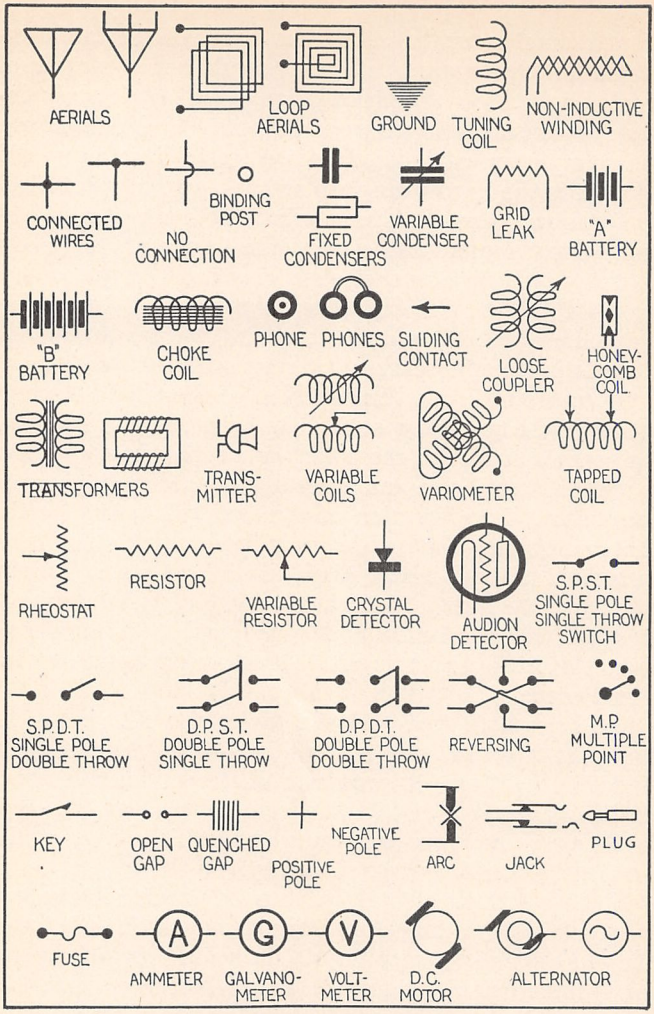
ground wire connects. Also the head phones are connected to the apparatus by a considerable strand of twisted wire. So the installation as a whole may involve a considerable network of wires; and certainly a tangible picture of it would not seem to bear any valid relation to the circuit diagram or hook-up here presented. That, as we know, is characteristic of hook-ups in general. They represent the principles involved, and show us the essentials as to electric circuits. They are not expected to look like the thing they represent, in a photographic sense, any more than rivers and mountains and cities look like the marks that represent them on a map.

Of course the actual installation of the triode detector in our radio receiving outfit has been accomplished by fastening a socket to the panel, connecting battery wires to designated posts; and inserting the triode itself into the socket. In a fraction of the time taken to describe the maneuvers, the triode is in place, with grid-filament and plate-filament established; and we are ready to adjust the rheostat which is connected with the positive lead of the filament ("A") battery, so that we may light the lamp and bring it to the proper degree of incandescence.

We have been told that the life of the filament—and therefore that of the triode itself—will depend upon judicious lighting. A moderate degree of incandescence is always required or to be desired. If too much current is used, the filament will burn out quickly, and at the same time will not work efficiently.

Having brought the lamp to mild incandescence, we manipulate the tuning apparatus of our outfit quite as in the old crystal-detector days. There is opportunity for much more delicate tuning than was before possible, because of the greater sensitiveness of the triode.

The time will come, too, when we shall have occasion to challenge the current from the plate battery. Ultimately we shall call upon that current to aid us in the




A COMPLETE SET OF SYMBOLS

Introduced by way of recapitulation and for convenience of reference. Also, at the lower part of the cut, some symbols not hitherto presented are shown.

installation of a "regenerative" circuit; to say nothing of manipulations that will have to do with the linking of the plate circuit with new triodes to act as amplifiers. But for the moment we are content to have added a single detector tube to our outfit, thus increasing its sensitiveness perhaps tenfold; and enabling us to "tune in" for messages so feeble (inherently or because of distant origin) that the crystal detector could by no possibility have revealed them.

Step by step, by gradual stages, but without waste effort, we have built us a radio-receiving telephone outfit that has genuine efficiency. It is by no means the last word in radio outfits; but it is a strictly high-grade equipment, capable of doing anything that may reasonably be asked of a single-tube apparatus that is not complicated by additional mechanisms for utilization of the "regenerative" principle. Some day we shall come to that also, of course. But before we think of further changes, we shall do well to acquire practical skill in the manipulation of the triode detector. We may confidently expect that the experience thus acquired will stand us in good stead when we ultimately aspire to add "feed-back" circuit and amplifying tubes to our outfit.

## CHAPTER VI

## THE RESTLESS ELECTRON AND THE RADIO HOOK-UP

IN the course of our studies we have had occasion to examine a large number of outline pictures, or schematic diagrams, popularly called "hook-ups," which are essentially pictures of systems of wire network by which the various parts of the radio-transmitting or radio-receiving apparatus are linked together.

We have had our attention called over and over to the fact that electric currents pass in certain directions along these highways of wire, and that efficient operation—for that matter any operation at all—of our apparatus depends upon the correct adjustment of these highways. We have not had occasion hitherto, however, to pay particular attention to the highways in themselves, our interest having been focused on antenna and inductances and condensers and crystals and electron tubes that seemed the essential parts of our mechanism.

Of course we have not been unaware that the wire highways are important; but we have thought of them only casually, just as most of us in making a tour of Europe, let us say, think chiefly about the points of interest visited—cities, cathedrals, laboratories, art galleries, ruins—and comparatively little of the railway and trolley and taxi and airplane highways that link one attraction with another.

But we could not see the attractions if we did not take the right highway; nor would our radio mechanisms be of any significance at all unless the right wire-highways connected them. These wire-highways—that being the

point of our present discourse—are solely significant because they offer facilities of transit for a single traveler —the electron, or negative particle of electricity. It is in the capacity of electron-roads that the wiring mechanism of the radio transmitting and receiving mechanisms is now to be considered.

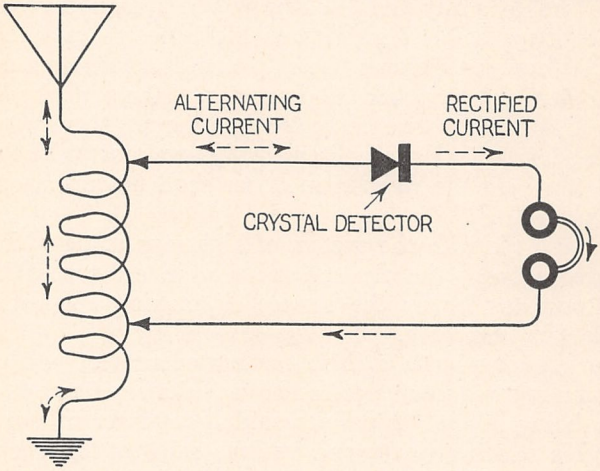
We are to study the hook-ups as a human traveler studies maps before he starts on his journey—at which time, as everyone knows, the ship line and railway line, and other highways are all important. Looking back, after the journey, we more or less forget them; but looking forward we are well aware that we must take the right boat and the right train or we shall not reach our destination.

And so it is with the system of highways along which we are to assist the electron traveler in order that he may perform for us the service of making our radio mechanism operative.

The analogy holds a little farther even; for, just as the human voyager may often have a choice of routes—there being several ship lines sailing to different ports from his starting point, and various railway lines connecting the different cities or groups of cities that he plans to visit—so the electron-voyager may on occasion be offered a choice of routes between, let us say, a certain inductance and a certain grid. And in one case as in the other, it may sometimes happen that the particular route chosen is a matter of indifference, since in any case the traveler will ultimately reach his destination. Yet it is also true that in each case there is usually one best route, that will permit voyaging most quickly, most directly, and with least expenditure of energy from one salient point of the itinerary to another.

The accomplished human traveler learns to choose the best route; and an accomplished radio operator learns to select the best route for the traveling electron,—he becomes, in other words, a good judge of hook-ups.

No one can become an accomplished traveler, however, who does not know just where he wishes to go; and no one can become an adept in hooking up of radio circuits unless he knows just what he wishes to accomplish. That is why it seems well, at this stage of our radio studies, to focus attention on the hook-up with reference




FLOW OF ELECTRONS IN THE CIRCUIT OF A SIMPLE CRYSTAL-DETECTOR RADIO-RECEIVER

Double-headed arrows indicate alternating current (A. C.); single-headed arrows, rectified, or direct current (D. C.), the change being due of course to the detector, which has the peculiar property of permitting free passage of electricity in one direction only.

to the wire-highways themselves, since we have gained a fairly intimate understanding of the more conspicuous mechanisms that are the points of departure and centers of attraction of the electron's itinerary.

In so doing, we shall naturally consider the matter from the standpoint of the traveling electron itself. Because, after all, it is the predilections of the electron that determine the workability of the entire mechanism.

There are certain rules of action that determine the conduct of the electron as a traveler, and from these the little voyager cannot be made to depart. Let us briefly inquire at the outset what some of these predilections are.

### THE ELECTRON AS WANDERER

We have already been sufficiently introduced to this amazing little entity to understand that the electron is not only the smallest thing in the universe (so far as we know) but also the most restless. It is activity personified. It perennially demonstrates not merely the possibility but the inevitableness of perpetual motion.

It is never still; you might fairly say that it would cease to be an electron—perhaps cease to exist at all—if it were for an instant to become motionless.

Not only is the electron perpetually aquiver—rotating on its axis, revolving in its atomic orbit—under conditions of what to crude human sense might be considered absolute fixity (as for example, when it is part of the atomic structure of what we call a solid that is a non-conductor of electricity—let us say a piece of wood), but it seems never content to move in this restricted orbit, and is perpetually endeavoring to break forth and go out to see the world.

Moreover, even under the conditions of what we would term greatest stability, it is forever succeeding,—as witness, in terms of human interpretation, the fact that chemical action is occurring everywhere and always. Such action, manifested in the slow rusting of a surface of iron or in the intermingling of chemical activities incident to the vital processes of living creatures, or the tangible reactions of a fire, or what not—are taking place everywhere and always; and every such action, interpreted in terms of our present study, implies a transit of electrons from one place to another. That, and that

alone, if we accept the verdict of modern scientific analysis.

The electron is the wandering Jew of the atomic world. Atoms, considered as such, and molecules considered as such, for the most part appear to be stable structures that very generally remain for a long time in one place, and seem not to be modified. But some of the electrons that are the unit structures of atoms are perennially leaving them and rushing off helter-skelter on this journey or that; the place of these wanderers being taken by other members, equally restive, of the same class.

And whenever such a migration of electrons occurs, there is evidence of it in what we human observers term an electric current.

We may or may not be able to detect or measure such a current; but, if our theories are right, the current is always there whenever the electrons travel. And as electrons never cease to travel, it follows that electric current never ceases to exist—anywhere and always and in every substance or structure in the world.

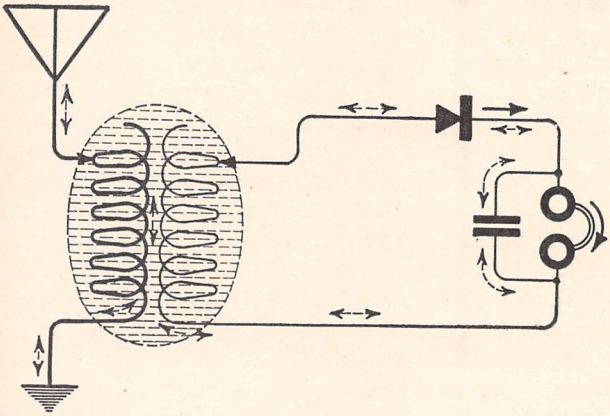
It does not by any means follow that every structure in the world furnishes as good a highway as every other structure for the journeyings of the little wanderer. The fact is far otherwise. Everyone knows that some structures give relatively free passage to electric currents, and that others are so-called dielectrics, forbidding free passages. And, in the present interpretation, that means that the former supply highways along which the electrons may move with relative celerity; whereas the latter form highways that are full of obstructions.

In practical radio mechanism, for example, as we are well aware, certain wires give free passage to the "current," and certain "resistances" offer obstruction.

More than that. There are various places in our radio mechanism where an air space occurs between the different circuits (as between primary and secondary coils of our various inductances), and we have learned that

electrons do not cross these air spaces at all—though they make their influence felt in the adjoining circuit with the aid of the "magnetic field" that always surrounds them.

If, now, we examine the electron's itinerary, or practical hook-up, more attentively, thinking of it in terms



FLOW OF ELECTRONS IN A CRYSTAL-DETECTOR RECEIVER WITH LOOSE-COUPLER AND BY-PASS 'PHONE CONDENSER

The shaded area indicates the sphere of inductive influence (which is not sharply delineated as in the drawing) between the two coils, there being no transit of electrons from one coil to the other. The by-pass (shunted) condenser permits the passage of unrectified portions of the current, which would meet undue resistance in the 'phones.

of easy or difficult electron highways, we shall see that there is one fundamental principle from which the electron traveler never departs. He seeks always the shortest route that will lead him to his destination. He never goes round Robin Hood's barn, if he can find a short cut.

True, he may make a detour just as the automobile traveler may make a detour—but for the same reason: the direct route is for the moment obstructed. The

circuitous route for the time being is the more facile highway. In automobile terms, the main road is torn up or out of repair; in electric terms, there is a resistance in the direct circuit, and the longer circuit will furnish the channel of least resistance.

It may be said parenthetically that the comparison between automobiles and traveling electrons must not carry us too far. For purposes of the illustration just given, the analogy holds; but if we are to gain a really clear view of electronic activities, we must recall that the electron voyager never has a clear road ahead, even under the best conditions, such as the human voyager has. Always the electron is traveling, or attempting to travel, in the midst of hordes of his own kind. His journey is not a solitary pilgrimage but the attempted migration of a vast population.

And the great difficulty is that the various members of the multitude are never agreed as to the direction in which it is desirable to travel.

There is perpetual jostling this way and that, and no one goes far without colliding with one or another of his fellows. So the truth about the little wanderer is that, as an individual, he does not journey far. It is only when we consider the entire mass of the population that there is a shift of habitat.

We speak of an electric current as flashing along the wire with the speed of light. In reality, what happens, if prevalent theories are correct, is that there is an infinite jostling among multitudes of electrons scattered the whole length of the wire, with the aggregate result that the individuals at the end of the line are thrust this way or that, this in human terms constituting flow of electric current; whereas each individual electron or group of electrons in the entire multitude, after being jostled a little distance this way and that, remains not very far from where it started. It has pursued a zigzag path, and has arrived nowhere in particular.

The net activities of the entire electron population in any given region of the circuit might be compared to the activities of a localized human population in a city or village, rather than to that of an individual human traveler who, let us say, goes to Europe.

### MUCH HASTE AND LITTLE SPEED

It is worth while to dwell a little upon this aspect of the electron's activities; chiefly because by so doing we shall perhaps come nearer to being able to visualize what takes place along the line of an alternating current; the kind of current, as we know, that radio deals with.

I know of no clearer picture of electronic activities than that presented by Professor J. H. Morecroft, in his book on *Radio Communication.* Let me then quote Professor Morecroft's account of what takes place along the wire or other "conductor" when what we term an electric current is "passing." Having defined the electron as the smallest possible quantity of negative electricity, and nothing but electricity, Professor Morecroft states that an electron in motion constitutes an electric current, and he presents a curious paradox as follows:

"The amount of electricity on one electron is so small that the current produced by one electron in motion would not be detectable by the finest current-measuring instrument, even the most sensitive. To produce currents of the magnitude occurring in every-day experience requires the motion of electrons measured in billions of billions per second.

"Contrary to what one would naturally think, the progressive movement of the electrons is very slow. To produce a current of one ampere in a copper wire one millimeter in diameter requires that the average velocity of electrons be only the one hundredth of a centimeter per second. And yet it must not be thought that the actual velocity of the electrons is small. If we assume

that "equi-partition of energy" idea of thermo-dynamics and thus calculate the average velocity of the electrons in a copper wire, at ordinary temperature, it appears that even when no current is flowing in the wire the electrons have a haphazard motion, due to the thermal agitation of the atom (or molecules), which gives them, on the average, a velocity of about 35 miles per second.

"Now when current flows the required progressive velocity of the electron is only a fraction of a centimeter per second; with a current so large that the copper wire is heated to the melting point the velocity of drift of the electrons is less than one centimeter per second."

(Electrons moving 35 miles per second, and progressing a fraction of an inch per second! A paradox indeed; but Professor Morecroft suggests an analogy by way of explication.)

"Suppose that we wanted to measure the rate of flow of people past a given point in a large city; the unit of flow might be 100,000 persons per hour. At any time there will be people going in all directions, some uptown, some downtown, some crosstown. In the morning a million people pass a certain point where the flow is to be ascertained. If 200,000 move in the uptown direction and 800,000 move downtown, the net flow is 600,000 people. If this number of people pass in one hour the flow is 6 units downtown. At noon time again a million people pass the same place, let us suppose; 400,000 move uptown, 400,000 move downtown and 150,000 move crosstown west and 50,000 move crosstown east. The net flow is 100,000 people west and if this number pass in one hour the flow is one unit west. Some of the people would be moving rapidly and others going more slowly and some might, at times, be standing still.

"The picture suggested by the above traffic analysis probably gives one a reasonable idea of the motion of electrons in a conductor carrying current; it is of course too simple; because of the immense number of electrons

in a conductor and the tremendous number of collisions occurring between the electrons. When a conductor is carrying no current the motion of the electrons resembles that of the individual in a stationary crowd, there is a deal of agitation among the electrons, but they, on the whole, show no progress along the conductor."

After reading such an account the amateur who was not previously well-grounded in the fundamentals is likely to look with new interest on the electron tube which is the very heart and brain—one is tempted to say the very soul—of both transmitting and receiving apparatus.

### ELECTRON MOVEMENTS IN RADIO TRANSMISSION

If for a moment we have thus focalized attention on the relative futility of the restless electron's activities, we must now change our point of view and consider not so much the waste motion of the little traveler as his ultimate achievements.

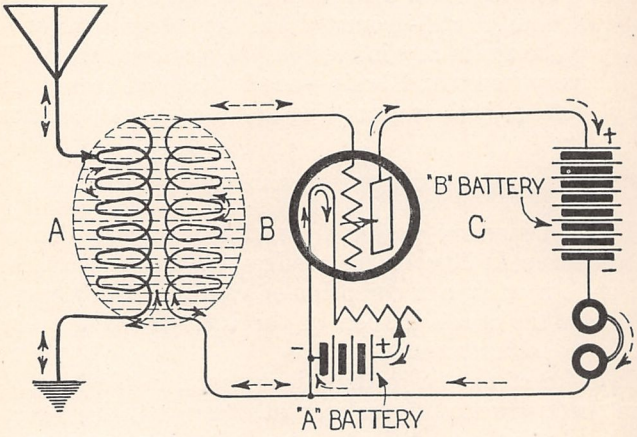
In spite of all the jostling, it appears, in the illustration just presented, there was at times actual progress of the electron population in one direction or another.

And in our practical radio mechanism, it is the aggregate progress that chiefly concerns us—though of course we are not unmindful of the practical obstructions that interfere with such progress. Indeed, it is by putting in an obstruction here and smoothing out the highway there that we direct the course of the electronic migration and make the mass movement serve our purpose.

For example, we erect an aerial, in order to obstruct electromagnetic waves coming through the ether, thus setting up a commotion in the electrons along the aerial antenna wire that will be manifested in a backward and forward surging between aerial and ground. But we do not permit the electron masses of the circuit to find their way to the grid even of the first electron tube. We send them circling about in the so-called primary of an in-

duction coil,—traveling round and round, like water in a whirlpool, and going nowhere at all.

So far as the particular swarm of electrons making up the aerial-ground circuit is concerned, that is the whole story. These can surge back and forth, but cannot escape from the end of the aerial on account of the in-



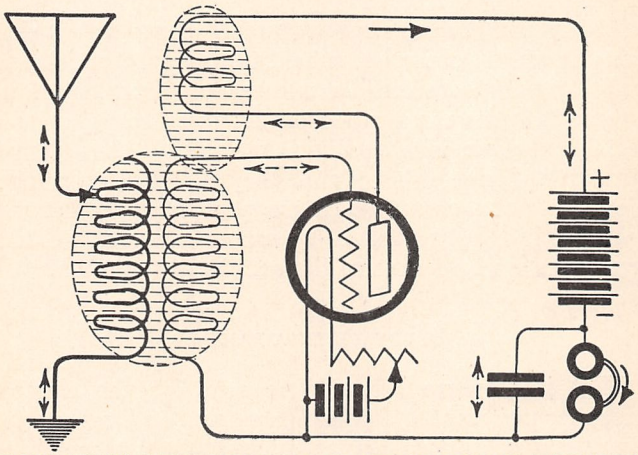

FLOW OF ELECTRONS IN THE CIRCUITS OF A TRIODE RECEIVER

Here are three circuits, A, B, and C, for the message-bearing current, in addition to the complete filament circuit. The input (grid) current is alternating (A. C.); the output (plate) current is direct (D. C.). Note the passage of electrons from filament to plate.

sulators; nor go far into the ground in the other direction, because the atoms that are robbed of electrons up in the aerial immediately become thereby positively electrified, and thus drag the escaping electrons back again.

But in the midst of the futile performance, it comes about that groups of electrons that are jostling this way and that in the coil of the primary located between aerial and ground are agitating each other with their magnetic lines of force; and this agitation is transferred to another

group of restless electrons in the secondary coil that is adjusted (in practical form of loose coupler or vario-coupler or honeycomb coil) not very far away from the primary. And this secondary coil is connected with wires that lead more or less directly in one direction to the grid, and in the other direction to the filament, of




FLOW OF ELECTRONS IN THE CIRCUITS OF A TRIODE-DETECTOR RECEIVING APPARATUS WITH "FEED-BACK" ARRANGEMENT

The shaded areas show the zones of inductive influence. The heavy single-headed arrow leaving the tickler coil is intended to indicate that the current is mainly rectified; while the double-headed arrows before and after suggest that rectification is not complete.

an electron tube, thus completing a circuit about which there may be a backward and forward surging comparable to that which is taking place in the other horde of electrons that we just left in the antenna circuit.

If a modern regenerative receiving radio outfit is in question, there is yet another association between the secondary coil and a so-called tickler coil that is adjusted in a third circuit, the terminals of which are the plate in the

electron tube and—as in the second circuit—the filament. And in this third circuit there is set up, initially by the action of the "B" battery, the restless surging of yet another multitude of electrons, which exercise an electro-magnetic, or inductive, influence over the electrons in the secondary circuit, thanks to the proximity of tickler coil and secondary coil.

And each of the three tribes of would-be migratory electrons, it will be observed, is held to its own atomic highway; and no considerable number of electrons of all three multitudes can escape from the metallic highways—because the air is a medium into which they cannot penetrate. Strive as they will, they are held at or near the surface of the road (each group in its respective wire system), just as we human beings in the course of our voyagings are held close to the surface of the earth.

### A VOYAGE IN A LAMP

That is why we are able to establish the electron itinerary represented by our hook-up, and make sure that it will be followed. Electron multitudes cannot even cross the little space that lies between the adjacent wires of one of our induction coils.

The thinnest film of air is an obstacle that opposes their utmost struggles like a veritable Chinese wall. Forward and backward they may surge along the narrow highway that the wire provides—but neither to right nor to left can they turn.

There is, however, one point in the practical highways that we are considering in the radio apparatus, where two groups of the electron voyagers come near together under new conditions. This is the region, in the interior of the electron tube, where the second and third circuits of our illustration virtually cross paths, the grid of one and the plate of the other, and the filament which they both share, being separated only by a narrow space—and

that space divested of the air that would still prove a barrier if it were present. For the electron tube is a vacuum tube. The air has been sucked out of it—the Chinese wall torn down. Nothing but ether remains (or at least we may ignore the fugitive corpuscles that have escaped the vacuum pump—though they really number about a hundred million to the cubic centimeter! —and ether is a medium through which the electron can travel, though by no means without difficulty.

And so it would seem at least possible that there should be a migration of electrons from the grid circuit to the plate circuit in the electron tube. But if such a migration occurs, it is of insignificant magnitude. It would perhaps take place at all only in case the wires of the grid became heated to incandescence through the proximity of the glowing filament,—for it is only from a heated metal surface that the electron can escape with any degree of facility. If electrons from the grid do make such escape, and find their way to the plate, their place in the grid-filament circuit must be supplied from the filament, to which in turn the traveling electrons come back through the plate filament circuit.

This is merely to say that we do not conceive it possible for an electron to escape from a given circuit, unless there is some way in which another electron may be brought into the circuit to take its place.

But in any event the input current in the grid circuit is a very feeble one, as we know; and in considering the migrations of electrons within the triode, the electrons that flow to the grid from the secondary coil, even though they are the important message bearers, are usually quite ignored. They are thought of as oscillating back and forth in the secondary circuit, between grid and filament, through the secondary coil, quite as if this little apparatus constituted a miniature antenna system. These oscillations are all-important, not because of the migration of the electrons in this circuit, but because of

their influence on the flow of electrons in a quite different circuit, or combination of circuits,—that which includes the plate and the filament.

The crux of the matter is that the filament constitutes a loop the ends of which are connected with a local battery, called the "A" battery, which sends a current of about one ampere through the filament, bringing it to incandescence. By "incandescence" we mean that the metal is brought to such a condition that its jostling crowds of electrons are made so preternaturally energetic that they actually jump off into space. Inconceivable billions on billions of them are making this effort to escape from the glowing filament, as from every other red-hot metal surface.

Such observation of the electrons, with resultant tendency to escape from their itinerary, happens in every electric-light bulb. The triode, in this regard, is no different from any other electric light. But in the ordinary electric-light bulb there is no opportunity for permanent escape of the electrons. There is no new circuit to which they can make their way; and they are drawn promptly back into the old channel by the attractive influence of the atoms that are made electrically positive by their absence. Also, the electrons tending to escape are repelled and driven back by other electrons just ahead of them that have got out a little way into the surrounding space. The principle that opposites attract and similars repel applies with full force in the world of the electron.

It is this principle that comes into play, with amazing results, in the little world of the triode, in which we at the moment are journeying. Having still in mind the horde of electrons attempting to escape from the incandescent filament, we have to consider the new influence exerted over them by grid and plate, the structures that differentiate the triode from the ordinary electric-light bulb. The grid, as we have just seen, is vibrant with

electrons that jostle backward and forward, making it first positive and then negative in potential in alternations of inconceivable rapidity. The plate is held at positive potential (as regards the filament), and at relatively high voltage, by the presence of the "B" battery, properly adjusted, in the new circuit of which it forms a part.

There is, then, possibility of escape of the electrons that fly out from the filament, either to the grid (in which case they would flow back through the secondary coil and ground to the filament again), or else to the plate (in which case they would flow out through the "B" battery and the telephones and, as before, make their way back to the filament).

In case of escape to the grid, however, these fugitives from the filament would serve no useful purpose, from the standpoint of the radio operator; but on the contrary would interfere with the incoming current, which bears the message. So it is desirable, in practise, to keep the grid at a potential so nearly equal with the filament that such a reverse flow of electrons (constituting "grid current") does not occur, or occurs to very slight extent.

But, on the other hand, the escape of the electrons from filament to plate (constituting "plate-current") is the one thing primarily to be desired, provided it can be properly regulated, in order that the plate current shall be of accentuated amplitude, and thus have a powerful influence over the diaphragms of the telephone receivers.

The basal function of the triode is to facilitate such escape of electrons from the filament loop to the plate in order to enhance, in a particular manner, the amplitude of current in the plate-filament circuit.

But please note that phrase, "in a particular manner." It is not at all sufficient that electrons should merely escape from the filament and be taken up by the cold, positively electrified plate merely to enhance the current

in the plate circuit. That current could be made of any desired degree of intensity merely by hooking up batteries of higher power. The particularity of the migration of electron swarms from filament to plate within the triode, lies in the fact that the character of this migration may be controlled by the grid.

If the grid were not there, the flow of electrons from the filament to the plate would be continuous and uninterrupted, so long as the plate potential remains positive; and the numbers of electrons entering into the migration would be determined by the degree of incandescence of the filament (under influence of the "A" battery) and the difference of voltage between plate and filament (as determined by the "B" battery). The fugitive electrons would simply scurry through the interstices of the grid, colliding with the wire of the little spiral more or less, of course, but for the most part continuing their journey quite as if no obstacle were present, —somewhat as water flows through the meshes of a sieve.

But when the grid is electrified (as by the flowing in of the message-bearing current), all this is changed. The alternating current makes the grid first positive, then negative, as regards the filament; and so at one instant it tends to attract the electrons that are flying out from the filament, and facilitate their flight toward the plate; and at the next instant, totally reversing its influence, it tends to repel fugitive electrons, and drive them back to the filament.

And thus, obviously, there results, through the influence of the grid, an intermittent instead of a continuous flow of electrons from the filament to the plate; and the current flowing out in the plate circuit is a pulsing instead of a continuous current. It is equally obvious that the pulsation in this current must be synchronous with the oscillations of the current that came to the grid— the message-bearing current; and that this is precisely what is to be desired in order that the telephone dia-

phragms should be influenced in harmony with the modulations of the input current.

A moment's reflection will make it clear that the influence of the grid will not consist merely in stopping altogether the flow of electrons from the filament in one of its phases and promoting that flow at a maximum in the opposite phase; but will undergo all gradations between minimum and maximum, in accordance with the varying amplitude of the input current. And this varying amplitude, obviously, represents the varied modulations of current at the transmitting radio station, corresponding to the vocal or other sound-waves impinging on the diaphragm of the transmitting microphone.

It is not enough that the plate-current should be a pulsating or direct current, instead of an alternating current; for its pulsations would still be at radio-frequency and thus would with difficulty flow through the resistant coils of the receiving telephone; it is essential that these pulsations should be of varying intensity, so that they are in effect aggregated into groups, the average variation of which amounts to larger pulsations constituting the waves that are spoken of as having audio-frequency.

The reader who wishes to attempt to visualize the tumultuous and helter-skelter activities of the electron mob representing such ever-varying changes of amplitude of the rectified current in the plate circuit, may find this an interesting exercise of the imagination. But doubtless most readers will be content to focus attention on what takes place within the triode, getting a clear notion of the essential fact of modification of flow of the electron throng from filament to plate under influence of the varying potential of the grid.

If we bear in mind that the jostling multitudes of electrons find it difficult to take on a reverse movement, from plate to filament, for the double reason that the plate is cold and is of positive potential, we shall still

more clearly realize why the plate current coming from the detector tube is a forward pulsing and not an alternating current. Without the influence of the grid, it would be a continuous current, having no effect on the telephone magnet unless artificially interrupted. Under influence of the grid it has become a pulsing or rectified current, of such modulated variations in amplitude as to influence the telephone diaphragms in a way to produce the desired response.

The pulsing electrons in this new circuit do not come into actual contact with the telephone diaphragms, of course. They merely come near enough to influence with their magnetic fields the permanent magnets that control the diaphragms of the telephone receivers; intermittently accentuating that influence as they jostle along the way and thus causing the diaphragm to be rhythmically pulled down and permitted to spring back into place at just the right interval to produce the air waves that will be interpreted as sounds by human ears.

### HARMONIOUS EVEN THOUGH TURBULENT VOYAGERS

That the jostling electrons moving along the plate-telephone highway should forge forward in the right numbers and pause at just the right intervals is a matter predetermined, as we have seen, by the intermittent arrival of new electrons at the plate, from the filament, in the electron tube; and such arrival is in turn predetermined by the character of the jostlings in the secondary circuit, which correspond to jostlings in the primary circuit that were superinduced by the impact of the electromagnetic waves coming from a transmitting station.

And in the transmitting station, were we to go back to it, we should of course encounter similar series of electron-itineraries, linked inductively at certain places, and at other places making actual connection in electron

tubes; until we arrived finally at the diaphragm of the transmitting telephone.

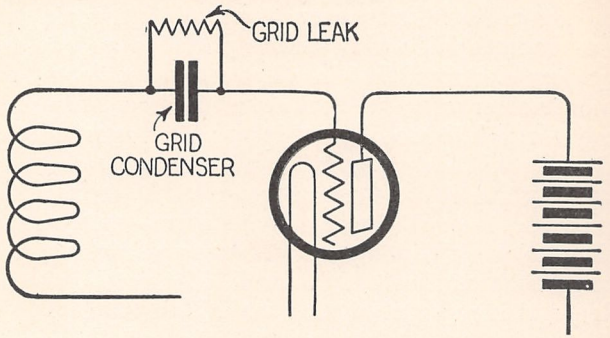
The interesting thing, from the present standpoint, is to reflect that in thus considering the hook-up of the receiving radio telephone and transmitting radio telephone we have to do with various phalanxes of would-be migratory electrons, that in effect relay a message from one to another, often without actual intercommunication except through the medium of intangible magnetic fields; and never with any possibility of personal contact between any one of the electron groups at the transmitting station and those at the receiving station—and yet with such team work that the relayed message arrives at its final destination absolutely unmodified (except in amplitude), and is reproduced with the utmost fidelity.

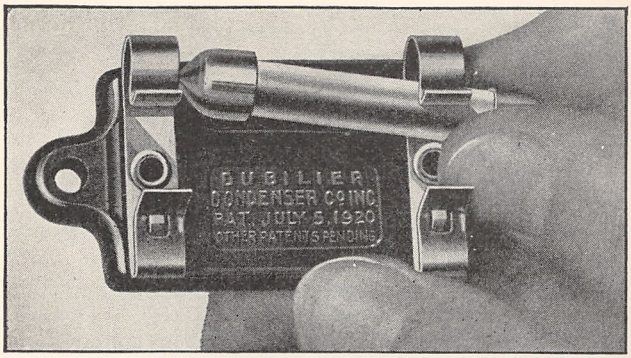
### GRID CONDENSER AND GRID LEAK

There is one minor highway of this strange itinerary that has been referred to but not dealt with in detail. This is the little detour accomplished through what has been named a "grid leak," in connection with the grid condenser. It is desirable now to learn something more about the apparatus which supplies this by-path.

With the operation of condensers in general, we are already familiar. The so-called grid condenser is merely a small fixed condenser introduced in the grid circuit. In practise, it is hooked in near the grid binding post. The input current passes through it, and its energy is stored and discharged in a way to aid in accomplishing the work of the detector tube, which was just examined in detail. Such a grid, as we shall see, is not introduced, as a rule, in connection with amplifying tubes, but only with the detector. Its action results in grouping the oscillations, thus aiding in a modification of the current from radio-frequency to audio-frequency. Parenthetically, it may be added that a similar condenser is

usually shunted across the telephones, in the plate circuit, to serve as a by-path for radio-frequency elements of the current that still persists, due to the imperfect rectifying action of the detector tube.



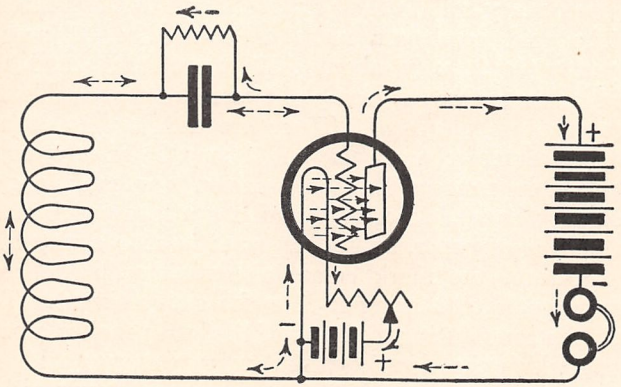




GRID-CONDENSER AND GRID-LEAK PRESENTED PICTORIALLY AND SYMBOLICALLY

In the photograph the tubular case that holds the little graphite rod constituting the grid-leak is being adjusted into the clips so that the grid-leak will shunt the condenser.

Our present concern, however, is not so much with the condensers, as with the grid leak that is shunted about the grid-condenser which we have just examined. This grid-leak is an absurdly simple mechanism. In a

specimen in hand, it consists of a little glass tube, with what looks like a pencil lead running down its center, with metal ends that connect with little metal posts projecting from the grid condenser that we have purchased to place in our improved radio-receiver. The hook-up shows how it is shunted about the condenser. In effect, it is a resistance, and a really powerful one,



FLOW OF ELECTRONS IN THE CIRCUITS OF A TRIODE-DETECTOR RECEIVER WITH GRID-CONDENSER AND GRID-LEAK

The grid-leak permits the escape of electrons that otherwise might pile up on the grid, making it unduly negative, and thereby interfering with the flow of current in the plate-filament circuit.

notwithstanding its insignificant size. It is rated at one megohm,—a million ohms. The feeble input current will pass through the condenser, and this by-path will have no concern for the electrons thus voyaging.

The voyagers that are concerned with the grid leak are the electrons that may accumulate on the grid, there in the triode, during its positive phase, tending thus to make it permanently negative,—of far greater negative potential than is to be desired, since in this condition, as

we know, the grid repels the electrons that flow from the filament, and thus shuts off the plate current.

Thanks to the grid leak, the electrons thus accumulated on the grid have an avenue of escape, without interfering with the action of the grid condenser. The grid leak furnishes a channel through which they may "leak off" the grid, and make their way back, through the secondary coil, to their original home in the filament.

The grid condenser must of course be of proper capacity (ordinarily about .002 microfarad), and the grid leak may have a rating of two megohms, double the strength just suggested. These are details that do not at the moment concern us; but it may be of interest to mention in passing that on occasion a substitute grid leak may be made merely by putting a lead pencil mark on a sheet of paper, and adjusting it in such a way that the ends of the mark come in contact with the condenser posts that bring it into the shunt circuit. The graphite constituting the mark of the lead pencil is a path along which the electric current may pass, yet a highly obstructive path, constituting a relatively strong resistance. The difficulty may be made greater or less by strengthening the pencil mark on one hand, or by partly erasing it on the other.

Another substitute grid leak may be made by saturating a piece of paper with India ink, and then cutting from it a small strip after it has dried. In each case, it is easy to modify the strength of the improved grid leak. In the apparatus as ordinarily purchased, it is easy to substitute one grid leak for another to test the needs of different circuits.

### A RETROSPECTIVE VIEW

Expanding our view again now, to take in the entire apparatus, and holding to the view of the moment according to which this is an intricate highway for wandering

electrons, we are led to wonder more than ever at the strangeness of the phenomenon involved. What figment of imagination could match this story of successive multitudes of eager electrons, in inconceivable numbers, crowding along endless narrow highways of man's construction, and ultimately carrying out the weird, fantastic human purpose of nullifying space?

And, coming back to things utterly practical, how better could we gain a clear conception of the action of radio mechanism than by thus following in imagination the activities of hordes of migrating electrons?

Stated otherwise, how better could we prepare ourselves to understand a practical "hook-up" when we view it, than by such a study? How otherwise could we so well prepare ourselves to invent new hook-ups for ourselves; to make new experiments with our radio apparatus; perhaps to become discoverers of new principles?

It was by such experiments, after he had become a trained electrician, that Dr. Lee DeForest was led to put the grid into the Fleming valve and thus make the audion; it was by such experiments, after he too had become an accomplished electrician, that Edwin H. Armstrong was led to develop the feed-back circuit, thus fortifying the secondary current and making the secondary coil regenerative.

And it will be by the use of the scientific imagination fortified by such visualizings as we have just been attempting that the discoverers of the future will make new, and perhaps now almost undreamed of, perfectments of the already marvelous radio apparatus.

Meantime, it remains for us to consider certain radio hook-ups somewhat more complicated than any we have hitherto examined, in order that their aid may make further improvements in our radio-receiving apparatus. Already we are coming to feel that the single detector tube in our outfit leaves something to be desired. Always there is something a little farther off that we would like

to hear. And then there is the matter of a "loud speaker" to make the lecture and concert audible to the whole family at once. We are told that this cannot be used except on an apparatus that has at least one stage of "amplification"—preferably two or three stages.

So now we are interested in regenerative circuits and triode amplifiers. To the consideration of these ultimate perfectionments of our radio receiving apparatus we turn in the ensuing chapters.

## CHAPTER VII

## THE REGENERATIVE AND AMPLIFYING RADIO RECEIVER

WHEN we took the crystal detector from our radio receiving apparatus and put in its place an electron tube, we may be said to have graduated out of the novice class of radio practitioners. So long as we dealt only with crystal detectors, we were hampered by a primitive mechanism, the limitations of which are clearly defined. But when we secured a vacuum tube, we were introduced to a mechanism that represents the ultimate present-day achievement of radio art.

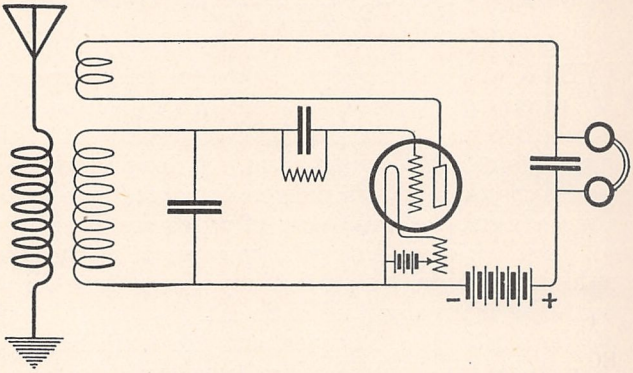
We were told then, however, and the truth has been reiterated, that a single detector tube could not reveal the utmost possibilities of radio reception; and we are now to inquire what we can do to supplement this effort. But in making this inquiry we shall be introduced to no new type of mechanism; no new principle except as exemplified in the action of the triode itself under modified electrical conditions.

We shall learn that the "regenerative" circuit, of which we have heard, would have no significance except as interpreted by the electron tube; and that the further amplification of the incoming radio message is effected through the unique action of a triode or series of triodes differing in no essential mechanism, but only in details of construction, from the detector triode with which we have already become familiar.

First of all, we have to consider the application of the

principle of the "regenerative" circuit as it may be introduced into our present tube-detector apparatus, without changing any of its existing parts, but merely by a relatively insignificant addition.

To show what this addition is, we turn to the hook-up which, after a moment's reflection, we shall recognize as representing our own radio receiving apparatus, as previously depicted; except that there is a coil added at an-




FEED-BACK CIRCUIT WITH TICKLER COIL

This is a basal form of Armstrong regenerative circuit. The essential feature is the introduction of a coil, called "tickler," in the plate-filament circuit, inductively related to the secondary coil of the grid-filament circuit. Energy is thus "fed back" from the "B" battery to the grid (input) current.

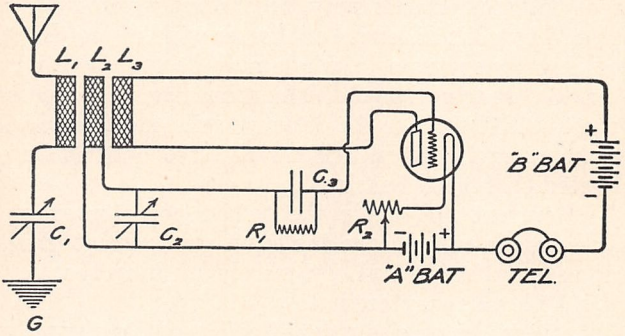
other part of the diagram, represented as introduced in the wire leading from the plate to the "B" battery.

In other words, a coil which we understand to represent an inductance has been introduced in the plate-filament circuit. And the position of this coil appears to put it in mutually inductive coupling with the secondary coil of our loose coupler.

We can only interpret this as meaning that when the apparatus is in operation, current flowing in the plate-filament circuit must inductively influence the current

flowing in the secondary coil, which of course is in the grid-filament circuit.

Such an interpretation is quite correct; and if we were to follow the hook-up and introduce a simple coiled inductance between the plate and plate battery of our outfit, placing it near enough to the secondary coil of our loose coupler to make the magnetic fields overlap, we should constitute our outfit a "regenerative" receiver. Our new




REGENERATIVE CIRCUIT WITH HONEYCOMB COILS

This circuit differs in no essential from the one shown in the preceding figure. It is introduced to illustrate the convenience of the honeycomb coil mounting as a feed-back mechanism. $L_1$, primary; $L_2$, secondary; $L_3$, tickler; $R_1$, grid leak; $R_2$, rheostat. Variable condensers, $C_1$ and $C_2$, are introduced in primary and secondary circuits.

circuit would constitute a simple example of the Armstrong "feed-back" circuit of which we have heard; and the new coil would be called a "tickler" coil.

We can make this tickler coil for ourselves, as we made the original inductance and the loose coupler, by winding a coil of wire about a hollow tube. We may tap the coil from place to place, to make it variable, as we tapped the others. We shall then have a home-made regenerative apparatus that will function admirably.

If, however, we wish to be very much up-to-date, we

can remove our loose coupler from the panel, and put in its place the mounting for a honeycomb coil, with the description of which we are already familiar. It will be recalled that this apparatus has sockets for three individual coils. Two of these of course represent the primary and secondary of the loose coupler. The third represents the tickler coil with which we are now concerned.

One advantage of the honeycomb coil is that the different individual coils may be instantly removed and replaced by coils of longer or shorter winding, so that the receiving apparatus as a whole may be tuned for waves of widely varying length. Meantime, as we have seen, the mutual influence of the different coils may be modified by changing their positions, as the two outer coils are adjusted on hinged bearings.

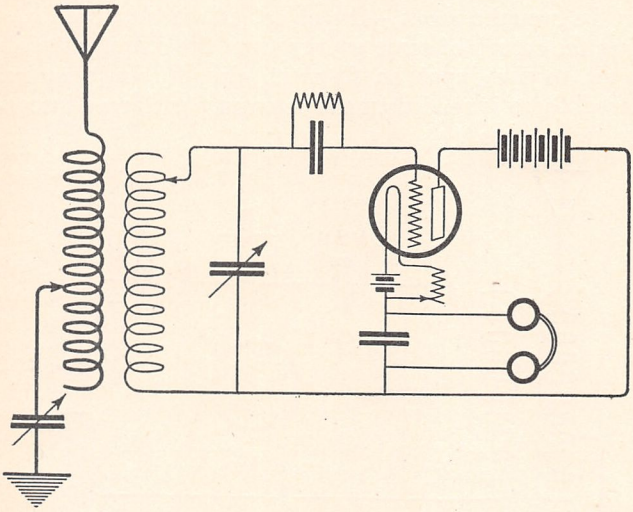
The current flowing in the tickler coil, for example, may be made to influence the input grid current more or less, as may be desired, by merely pushing the tickler coil a little this way or that.

Whatever the precise type of coil used for the tickler, however, the influence that it exerts may be highly important. In effect, the tickler establishes a new circuit, joining plate and grid in a new relation. The plate, as we know, is held at relatively high potential by a 22½ volt "B" battery. The electrons from the filament flow out of the triode through the plate in partly rectified pulsations synchronous with the oscillations of the incoming grid current, under this relatively high voltage; and the current thus flowing through the tickler coil stamps its influence inductively on the input current coming through the secondary coil to the grid.

But this, of course, is the message-bearing current; and the statement just made is equivalent to saying that this message-bearing current is fortified by the influence of the high-voltage plate current. Energy from the plate-filament circuit is "fed back" to the grid-filament circuit.

As the pulsations of the plate current, although recti-

fied, are synchronous with the oscillations of the input grid current, the effect will be to amplify the latter. Then the amplified voltage in the grid in turn accentuates the flow of electrons from filament to plate,—enabling the plate current, of course, still further to amplify the input (grid) current by the feed-back route.



ANOTHER TYPE OF INDUCTIVE REGENERATIVE CIRCUIT

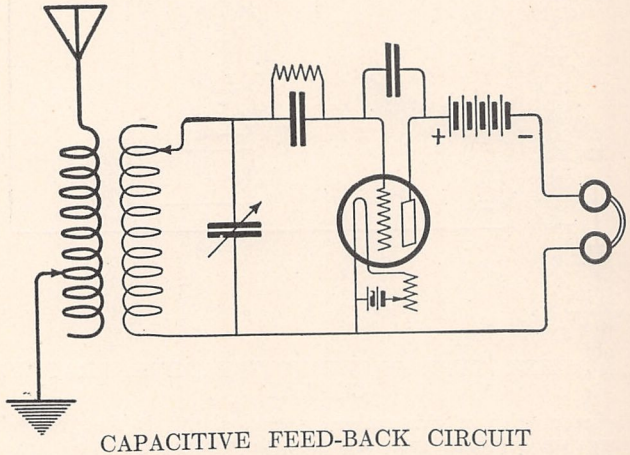
The peculiarity of this rather unusual circuit is that the telephones are brought into the secondary circuit as well as the plate-filament circuit. This arrangement illustrates the wide scope of the Armstrong patents which, as some one has facetiously said, cover "almost everything but the hinges on the receiver case."

Thus plate current boosts grid current by tickler-coil induction; and grid current boosts plate current by grid influence in the triode; and this mutual influence, repeated over and over, the two forces acting in the same direction, gives one a curious sense of something akin to perpetual motion. We know, of course, that no physical laws are

being violated, but the practical results are startling, fully justifying the designation "regenerative" as applied to such a circuit.

### OTHER METHODS OF REGENERATION

There are various other ways in which regeneration may be brought about,—the object attained in each case being the return of some energy from the output or plate circuit to the input or filament circuit. In technical phrase, there is readjustment between positive and negative resistances.



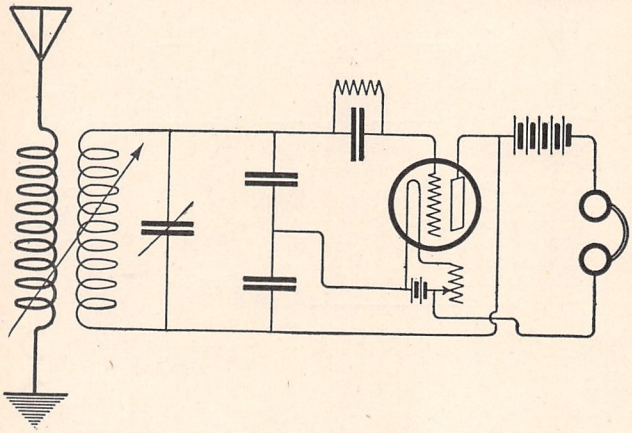

CAPACITIVE FEED-BACK CIRCUIT

Here the introduction of a fixed condenser shunted between grid and plate serves to effect "regeneration." This is a less popular circuit than the inductive feed-back.

The method just described is spoken of as inductive coupling. It is possible to use capacitive coupling instead, by shunting a variable condenser between the plate and grid directly, or with a pair of variable condensers shunted across a larger circuit linking the plate with the grid by the roundabout way of the secondary coil. Cir-

cuit diagrams here reproduced will serve better than a description to give details of such an arrangement.

The more familiar method of accomplishing regeneration, however, and one that has gained popularity with amateurs, is what is called the tuned-plate circuit. Here a variable inductance, usually a variometer, is introduced in the plate circuit, and tuned to the frequency of the



ANOTHER TYPE OF CAPACITIVE FEED-BACK

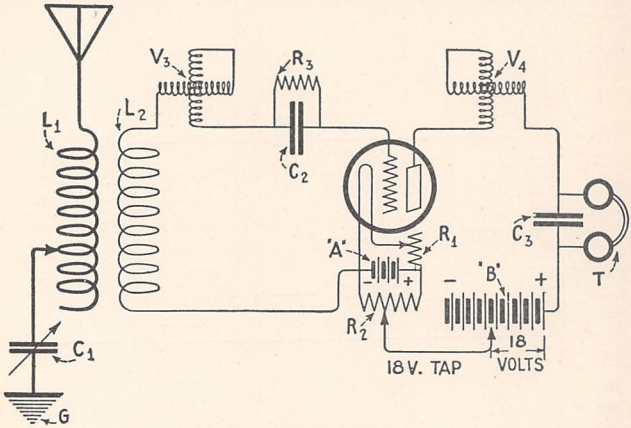
Here two fixed condensers are introduced in a rather intricate combination, in double relation to the grid and plate circuits. This circuit is commended only for the somewhat advanced amateur who likes to experiment.

input circuit, which in itself increases the strength of the signals. But in addition to this, the variometer serves to oppose changes in plate potential; and this in turn affects the grid potential because the grid is in the electrostatic field between plate and filament in the triode.

The variation of the grid potential thus brought about is of a character to augment variations in current; and such augmentation of variations is the essential feature of regeneration.

We shall perhaps understand the effect better if we

reflect that an inductance opposes changes in current,—either starting or stopping. By "positive resistance" to the starting of plate current, it enhances the influence of the negative phase of the grid; and by "negative resistance" to the stopping of the current it enhances the influence of the positive phase of the grid. Thus the plate current is brought to a lower minimum during the negative




A "STANDARD" REGENERATIVE CIRCUIT

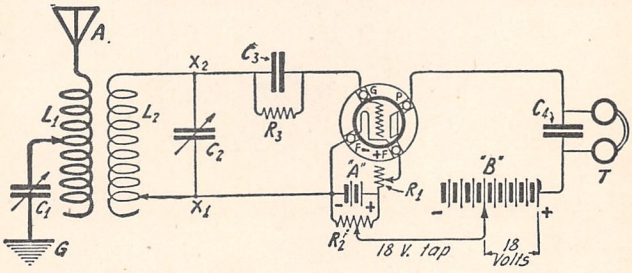
Using a vario-coupler ($L_1$ $L_2$) and two variometers ($V_1$ $V_2$). In addition to the usual rheostat ($R_1$) controlling the filament current, there is a type of resistance called a voltage-divider, or potentiometer ($R_2$), to put a negative bias on the grid by controlling placement of potential from the 18-volt tap of the "B" battery.

phase of the grid and to a higher maximum during its positive phase than would be attained without the aid of the auxiliary inductance.

A combination that has proved so effective when the short waves mostly used by amateurs are in question that it has come to be spoken of sometimes as the standard regenerative circuit, supplies a vario-coupler as the primary inductance, with a variometer in the plate circuit as just suggested, and with a second variometer in the

input or grid circuit. An additional refinement, of value in this and many other circuits, is the introduction of a voltage-divider, often spoken of as a potentiometer, used in addition to the customary rheostat in connection with the grid-filament circuit.

This apparatus is in effect a variable resistance, not unlike a rheostat in appearance, but having a third binding post connecting with the sliding contact that "divides"

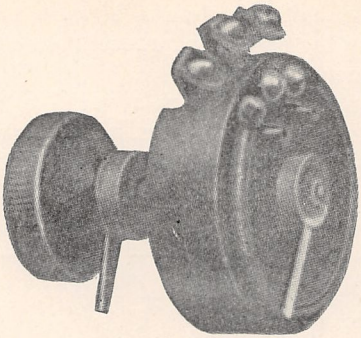


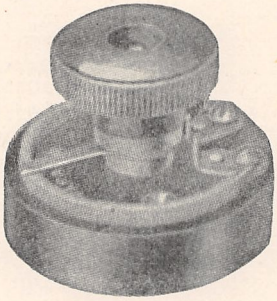

A NON-REGENERATIVE CIRCUIT USING A POTENTIOMETER

The potentiometer ($R_2$), or voltage-divider is introduced precisely as in the circuit shown in the preceding figure, and for the same purpose. The photographs (overleaf) show the potentiometer, and a rheostat for comparison. The two are very similar in general appearance, except that the potentiometer has a third contact post.

the voltage. Shunted across the "A" battery with the slider connecting with an 18-volt negative tap of the "B" battery, a potentiometer can be used to regulate potentials in the grid-filament circuit; the ultimate object being to maintain the grid voltage at the right point for best operation of the triode.

There is yet another method of regeneration which differs from the ones just described in that it does not call for the introduction of an auxiliary equipment in the circuit. It is called the ultraudion, and is chiefly of value for long-wave reception. A peculiarity of the hook-up is that the wire from the secondary coil that usually goes

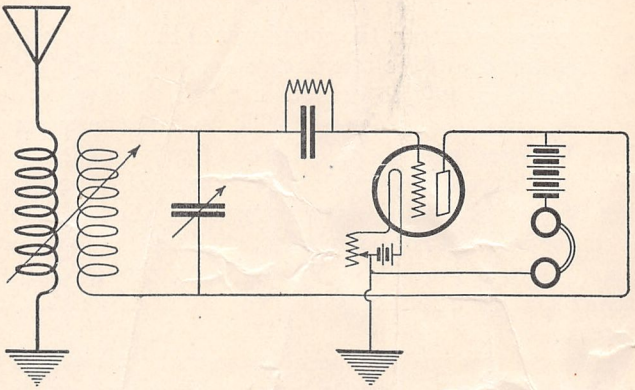




POTENTIOMETER AND RHEOSTAT

Each is in effect a variable resistance; but the potentiometer is also a voltage-divider, giving a negative or a positive bias as the contact lever is shifted.

to the filament is carried to the plate instead; so that there is a direct plate-filament circuit that does not involve the plate and filament batteries in the usual way. The action is facilitated by grounding of one side of the filament battery. The effect is explained as capacitive. The arrangement has the merit of being readily tested, and as readily shifted back to a non-regenerative circuit;



THE ULTRAUDION REGENERATIVE CIRCUIT

It will be seen that one end of the secondary coil connects with the grid, as is usual; but that the other end connects with the plate instead of passing to the filament. The filament circuit is directly grounded. This circuit is generally regarded as better for long-wave than for short-wave reception.

but it has not the interest for the average amateur that attaches to the tickler coil and the variometer arrangements already described.

Let it be repeated that the essential feature of all these regenerative systems is that they "feed back" energy from the plate battery to amplify the input current, so that the more widely varying grid potential may in turn "boost" the synchronized plate current. A single detector tube, thanks to this principle, may amplify the current enormously even while rectifying it; and the pulsations

that pass through the telephone magnets have unprecedented force. And so, at the 'phones, we "listen in" on stations that hitherto were beyond the range of our receiver; and the messages from familiar stations are much louder than before.

### ADDING AMPLIFYING TRIODES

Even now, however, the sound waves that pulsate from the diaphragms of the telephone receivers are not ordinarily ample enough to actuate a "loud speaker" as effectively as could be desired. The message may sometimes be heard with the telephone a few inches from the ear; but, in general, satisfactory listening still requires that the pair of 'phones should be worn on the head. And of course we shall not be quite satisfied until we can have a loud speaker, and thus permit the radio receiver to entertain the entire family or a room full of visitors, all at once.

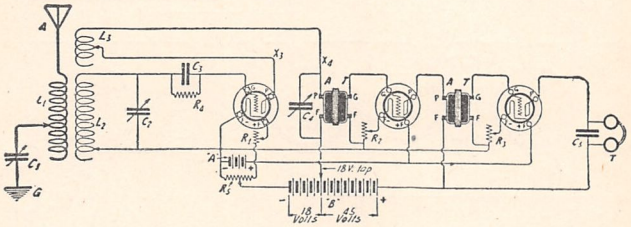
To make this possible, and also to make it possible to reach out to the farthest limits of the broadcasting field, we have been told, it is necessary to introduce "one or more stages of amplification." And now we are ready to make inquiry as to just how this may be done.

We are already aware that the "amplifier" to which we must turn is an electron-tube closely similar to the detector that we are using. We now learn that the two may not differ at all in appearance, even when closely inspected. The actual difference, we are told, consists in the fact that the amplifier is a "hard" tube,—that is to say, one in which the air has been more nearly exhausted, so that it constitutes a "higher" vacuum. A "soft" tube has been found to work better as a detector; the "hard" one is universally admitted to make the better amplifier.

So if we provide ourselves with two of these amplifying tubes, what now are we to do with them?

A glance at the new hook-up will give us the answer.

Here we have, as regards the main portion on the left, a reproduction of the hook-up last shown, which represents our outfit with its "feed-back" addition. But now at the right we observe that two triodes, which of course represent the amplifiers, have been inserted, involving the addition of some diagramatic figures that might prove confusing.




REGENERATIVE CIRCUIT WITH TWO STAGES OF AUDIO-FREQUENCY AMPLIFICATION

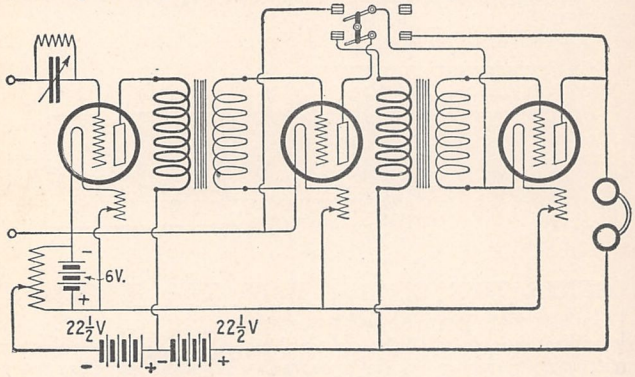
The left-hand moiety of the figure shows the familiar tickler-coil circuit, with detector triode operated with rheostat and potentiometer. Instead of telephones in the plate circuit, at the right, we find an audio-frequency transformer, followed by an amplifying triode; and this combination repeated. A single "A" battery supplies the three filaments. The single "B" battery is tapped, to permit lower voltage on the detector tube than that supplied the amplifiers.

The figures in question, depicted as a pair of coils with some parallel lines between, represent iron-cored transformers,—a species of induction coil fundamentally similar to the various couplers with which we are familiar; but differing as to the iron core, which facilitates magnetic action; and in the important detail that the secondary coil may contain a larger number of turns of the wire, in order to "step-up" the voltage of the induced current.

It will be observed that the primary coil of the first transformer occupies a position in the diagram closely comparable to the position of the head telephones in the earlier diagrams. In other words, the current flowing

from the plate of the detector tube, instead of passing to the telephone receiver, passes through the primary coil of the first transformer.

The current from the secondary coil of the transformer passes directly to the grid of the first amplifying tube. And this sequence is repeated between the first and second amplifiers; the current from the plate of the final




DETECTOR AND TWO-STEP AUDIO-FREQUENCY AMPLIFIER

Here we have, as in the preceding figure, a detector tube with two transformers and two triodes added for audio-frequency amplification. We shall see later that this outfit might be hooked up by the open leads at the left to one or more radio-frequency amplifying tubes and transformers. On the other hand, it is complete in itself if the leads are attached, in the usual way, to the tuning coil. Note the double-pole double-throw (D P D T) switch giving added flexibility.

amplifier passing through the head telephones—as the current from the plate of the detector tube would have done directly had the amplifiers not been introduced.

This arrangement, which is simple enough when explained, is termed placing the tubes "in cascade." It will be observed further that the filaments of the successive tubes are fed from a single battery, the positive lead in each case being provided with a rheostat for control.

The negative poles of the battery connect ultimately with lines that complete the plate-filament circuits and the grid-filament circuits. So the seeming complexity, due to a multiplication of lines, involves no actual complications that introduce a new principle of electrical action. By the exercise of a little ingenuity, we can map out the itinerary of any particular group of electrons with reasonable certainty.

And this is another way of saying that we can follow these items of the hook-up in wiring the two transformers and two amplifying tubes that we have purchased into the circuit of our enlarged and perfected radio-receiving apparatus.

Practical points to be borne in mind are that all wires should, so far as possible, be so distributed as to avoid paralleling one another; and that the transformers should be placed rather far apart and at right angles to each other. All this, of course, to avoid so far as may be the disturbing influence of unwelcome inductive and capacitive effects.

### THE WIZARDRY OF THE AMPLIFIER

And now at last our efforts have brought us to what might seem the end of the road. We have a really up-to-date and highly perfected radio receiving apparatus, with regenerative circuit and two-stage audio-frequency amplification. Properly operated, it will bring messages of infinitesimal tenuousness to our ears, magnified to full audibility. It may reach out a hundred miles or twice or thrice that, under favorable conditions, for telephone messages; and for the reception of telegraph signals its possible range is almost without limit.

And yet this really wonderful radio receiver of our own manufacture, amplified now to such amazing capabilities of action, is a physical structure occupying a panel scarcely more than two feet in length and perhaps a foot in breadth. Even if the batteries were assembled,

the entire apparatus would find room on a small table, or a moderate mantle shelf.

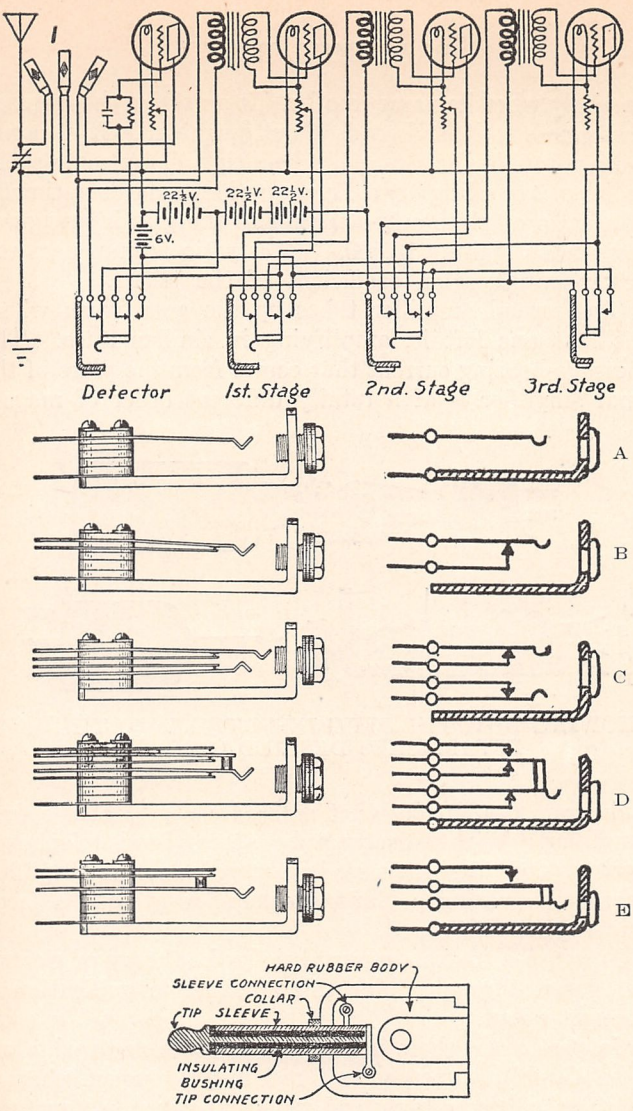
Even the antenna, now that we have so sensitive a receiving apparatus, might be minimized. If we chose, we could unhook the aerial, and substitute a loop antenna five or six feet across that could stand on floor or table or could be suspended from the ceiling.

The function of the big antenna was simply to expose a relatively large surface to the electromagnetic waves, to absorb the largest possible amount of energy, because the receiving apparatus was relatively weak.

At the very best, only an infinitesimal amount of energy can be thus waylaid and made subject. With the relatively non-sensitive crystal detector, it would be futile to attempt to operate without a good-sized aerial. Even with a single detector triode, the energy received by the conventional aerial is none too strong for handling. But when regenerative circuits and amplifying tubes are in question, the amount of magnification that can be brought about is so notable that currents far too feeble to be recognized by a crystal detector or even by a single tube detector can be effectively handled.

More powerful current will be handled better still, of course. There is no mystery about the thing. The big aerial is not necessarily to be given up because we have the amplifying apparatus. If we were to give it up, depending only on the loop, our perfected amplifier could by no means reveal its full possibilities. It might serve little better than the crystal detector, aided by the full-sized aerial, would serve. But it does make it possible to dispense with the cumbersome aerial when only relatively loud messages, as from a broadcasting station fifteen or twenty miles away, are in question; and this is sometimes highly convenient for the city dweller.

Meantime, as we have seen, the amplifying receiver handles all types of messages with efficiency that the simple apparatus cannot approach. The amplifier does

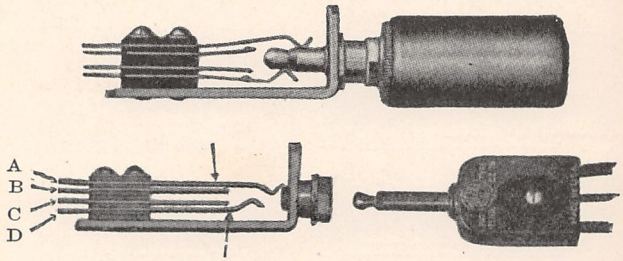



JACKS OF VARIOUS TYPES, AND PLUG SHOWN IN DIAGRAMMATIC SECTION

Above, honeycomb-coil receiver that may be used as a simple (regenerative) detector or as one-step, two-step, or three-step amplification (audio-frequency) by putting the telephone plug in the appropriate jack.

precisely what its name implies. It amplifies the message that comes to it, and sends it out magnified. It does not merely double the strength or multiply it by some small factor. According to a Bureau of Standards estimate, "the ratio of plate output power to the grid input power may be as high as 10,000." This ratio is known as the power-amplification coefficient of the triode.

The second amplifier takes up the good work where the first one left it, amplifying in similar ratio. The message-bearing current that comes from the plate of the final amplifier is of a totally different order of magni-




SHOWING HOW THE PLUG INSERTED INTO THE JACK ESTABLISHES DESIRED CIRCUITS

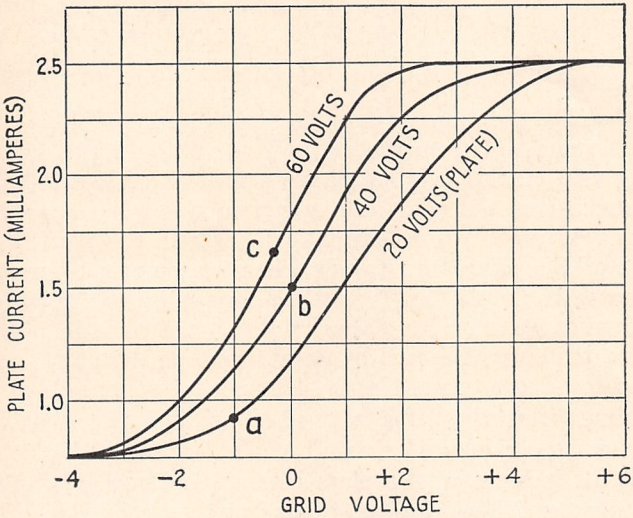
tude from the current that entered the grid of the first amplifier. With detector tube alone, head telephones perhaps made the message barely audible; the amplified current, actuating a "loud speaker," may flood a large auditorium with sound.

It remains to explain very briefly the theory of electrical action through which this amazing magnification is brought about.

In particular, there is a puzzle to solve as to why one tube should act merely as a rectifier of current whereas another tube, seemingly and in fact identical in structure, should serve preëminently to amplify the current without otherwise changing its character.

THE "CHARACTERISTIC CURVE" OF THE TRIODE

The question is one that does not puzzle the tyro alone. Expert electrical engineers without number have pondered over it, often without finding an answer. Perhaps it would be too much to say that there is full agreement




THE CHARACTERISTIC CURVE OF THE TRIODE

It will be seen that the sharpness of the curve varies with different plate voltages. There is also marked difference between tubes. At point *"a"* the tube operates as detector, a negative shift of grid potential practically shutting off the current, whereas a corresponding positive shift accentuates the current tremendously. On the other hand, operated at points *"b"* or *"c"* current is not shut off with changed grid potential, and the tube amplifies but does not rectify the current.

to-day as to all details of action of the necromantic electron tube. But, on the other hand, there is a consensus of opinion that makes for at least provisional acceptance of a theory of action of the triode, whether as rectifier or as amplifier, that has the merit of plausibility.

The theory is based on studies that reveal certain definite relations between the flow of current in the plate circuit (the outflow from the tube) and the conditions of electrical potential, so-called, as existing between the grid and filament. A graphic diagram may be drawn, to represent what is called the normal valve action, or "characteristic curve," of the triode. Inspection of such a diagram makes it possible to visualize conditions of electrical activity in the tube in a manner highly informative.

Briefly, the diagram may be thus interpreted:

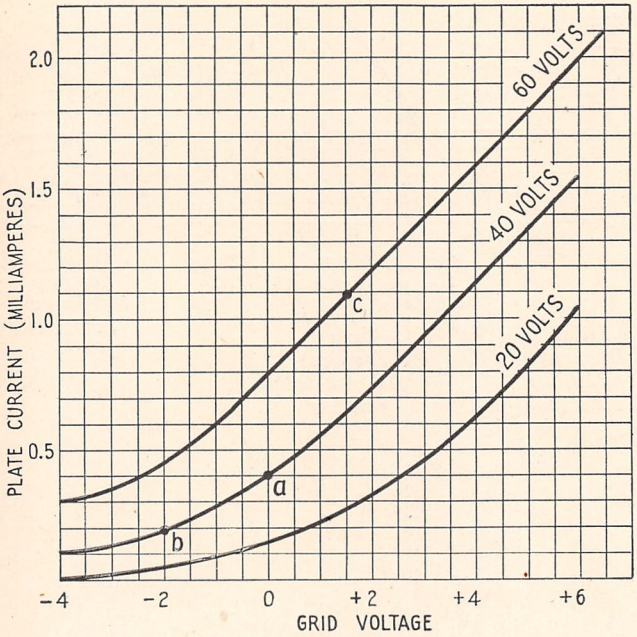
Assume a plate current of uniform voltage, and a varying grid current. If, as between grid and filament, the potential of the grid at a given moment is somewhat strongly negative, no current will flow in the plate. If the grid becomes less strongly negative, current begins to flow in the plate, but for a time only feebly. Presently, however, at a certain stage, while the grid is still negative, the current is rapidly accentuated in the plate, and the low-lying curve (in the diagram) is changed to a straight line that shoots upward at an angle not far from the perpendicular.

This increase of the plate current continues after the grid potential becomes positive; but then comes quickly to a maximum, beyond which there is no increase. Current in the plate has now reached the saturation point.

In terms of electron-flow, this is held to mean that when the grid is strongly negative it repels the electrons that fly from the filament, so that few can pass through its meshes to reach the plate; and that when it is moderately positive it attracts electrons from the filament sufficiently to facilitate their flight but not to stop them, so that a maximum number reach the plate. More strongly positive, the grid may hold electrons to itself, starting a grid-filament current, and checking the flow to the plate. At an intermediate stage, when the grid is mildly nega-

tive, just the right balance is struck, and a slight change may produce a very striking effect.

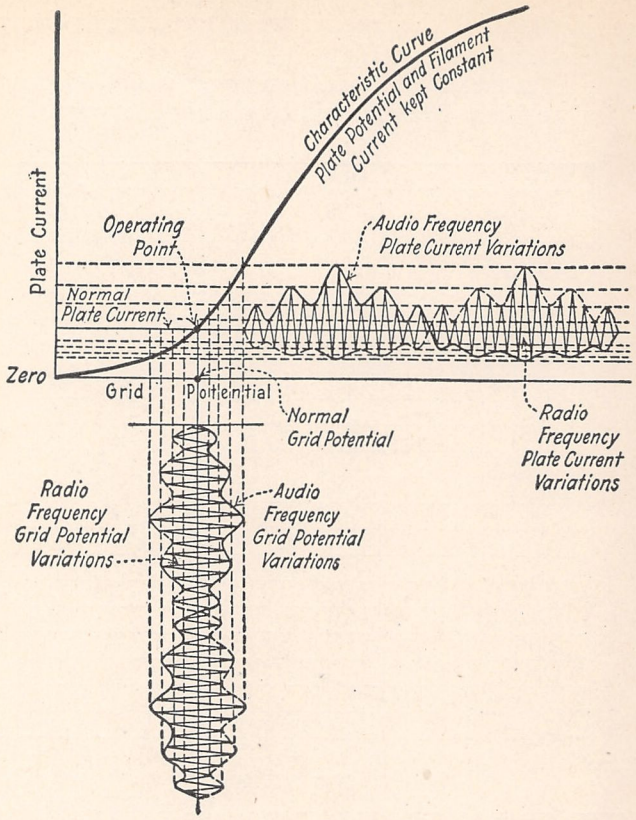
The point marked "A" on the diagram indicates such a critical position. Here, it will be observed, a very slight




THE CHARACTERISTIC CURVE OF THE TRIODE

Showing the advantage of operating an amplifying tube at high voltage (plate). At the points "*a*" and "*b*" there is rectification with slight amplification; at point "*c*," very marked amplification without rectification.

decrease of negative potential (shift to the right in the diagram), results in a very rapid rise in the plate current; whereas a corresponding increase in negative potential (shift to the left) results in far less significant decrease of current.




RECTIFICATION OF MODULATED CURRENT IN THE TRIODE

It will be apparent that the accentuation of one phase of the current and repression of the other phase results from the "characteristic curve" of the triode, when operated at the right point, as regards grid potential. The vertical part of the figure represents the uniform modulation of the voice waves as they come to the triode; the horizontal part, the modifications brought about by the detector triode. (Reproduced from *The A B C of Vacuum Tubes in Radio Reception,* by E. H. Levis.)

It must be obvious that if the tube is worked at just this balance of potentials between grid and filament, the effect will be to rectify the alternating current in part; inasmuch as for each positive phase of the current there will be a marked increase of plate current and for each negative phase a relatively slight decrease. But if the tube is worked at the point marking the bottom of the scale in our diagram, the positive phase of the current would be represented by enhanced plate current and the negative phase by cessation of that current. And this of course would be equivalent to complete rectification of the outflowing current.

In other words, under these conditions, the tube would act as a detector.

But now, if we wish to have the tube act as an amplifier, nothing more is necessary than to adjust the current in such wise that the grid is of the right potential in relation to the filament so that the tube is operating at the straight part of the characteristic curve. Even an alternating grid current (oscillating from positive to negative) will not then interrupt the flow of the plate current, but will cause it to oscillate in unison with the alternations of grid potential. Relatively slight changes of grid voltage, however, produce marked accentuation of the plate current, as the diagram shows.

A one-volt change in the grid may produce a five-volt or even a ten-volt change in the plate; the exact ratio representing what is called the "amplification constant" of the individual tube.

Just how high the voltage may be is determined by the local batteries and the transformers that lie between successive tubes. The secondary coil of each successive transformer establishes a new circuit; and this increase may be carried far, the filaments of the successive tubes being protected by variable resistances. The input (grid) and output (plate) circuits of successive tubes are hooked up at higher and higher levels and—strange as it

may seem—the pulsating current thus amplified maintains its essential characteristics of modulation, so that in the end it shakes the telephone diaphragms tempestuously and yet in just the right sequence to reproduce the movements of the diaphragm of the microphone at the distant transmitting station.

### THE HETERODYNE OR "BEAT" EFFECT

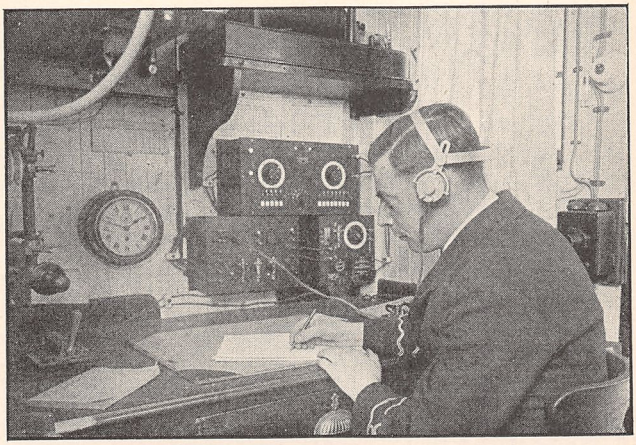
Such theoretical considerations enable us to gain at least an inkling of the way in which the electrons are juggled in the triode tube in attempting to maintain a balance of what the electrician calls potentials; which we may interpret as a shortage of electrons at one electrode of a circuit and a surplus accumulation at the other. The essential result is that a very weak input current is supplanted by a relatively powerful output current, thanks to accessions of electrons from the incandescent filament under influence of the local plate ("B") battery.

We shall have occasion to examine more at length in another connection into the capacity of the weirdly versatile electron tube to set up oscillations, and thus become an all-important part of the radio-transmitting mechanism. Here we are concerned with the receiving mechanism only. It must be noted, however, that even the triode of the receiving outfit, when used as detector, may have the balance of its electrical circuits so disturbed through operation of the regenerative circuit as to set up oscillations that may be transmitted to the receiving aerial, and constitute it a transmitting aerial as well—sending out disturbing electromagnetic waves, to the distraction of users of other radio-receiving outfits.

But on occasion the detector tube may be made to oscillate at a given rate as an aid to the performance of its usual function. Specifically, oscillations may be developed of a frequency purposely close to that of the incoming current in order to produce what is known as the

heterodyne or "beat" effect. Such operations may be set up in a separate tube, which is spoken of as a separate heterodyne; or in the detector tube itself, in which case the effect is said to be "autodyne," or self-heterodyne.

We shall examine more fully this interesting phenomenon in another connection; here it suffices to men-



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A MODERN RADIO RECEIVER ON SHIPBOARD

Chief operator F. W. Walsh and the receiving outfit of the liner *Vauban* which picks up messages at 11,500 miles. Every ship with a crew of fifty men is required to have a radio outfit.

tion it by way of preliminary; and it will be well to bear the names in mind for future reference. The heterodyne effect is highly important in the practical work of the advanced amateur, as we shall see.

It never ceases to be a matter for wonderment that the magic tube is able to receive ethereal messages of infinitesimal sensitiveness, and bring them finally to the listening ear as clearly audible sounds; or even, if desired, to transform an inaudible whisper into vibrations of a

million-fold amplitude and trumpet them forth like a volcanic explosion.

Expositors who have attempted to express the full capacity of the triode as a sound-amplifier, have said that it can deal with vibrations that correspond in weakness to the light-waves that come to us from a star; or that it can make the soundless footfall of a fly creeping along the ceiling seem to rival the tread of an elephant.

As another practical illustration, we may cite General Squier's demonstration, to be referred to elsewhere, in which the sound of a man's heart-beat is transmitted by radio waves (directed along a wire in this case, but that does not change the principle) and ultimately amplified by a series of triodes so that the "loud speaker" is clearly audible to a company of physicians or medical students in a large auditorium.

The quality that makes such things possible is, of course, the same quality that permits the audion-equipped radio receiving apparatus to pick up messages from stations hundreds or thousands of miles away. Messages are heard that come to the receiving antenna on waves incredibly attenuated; waves representing so infinitesimal a fraction of the generating energy of the transmitting aerial as to justify the comparison with the faint glimmer of starlight.

But no such feats would be possible,—nor indeed any consequential feats of radio telephony,—without the aid of the little implement which, in view of its multifarious and necromantic activities, one feels disposed to name as the most truly remarkable piece of mechanism that has ever been devised by human brain and human hand—the grid-bearing, three-electrode vacuum tube originally called audion by Dr. Lee DeForest, its inventor, but now semi-officially designated triode.

## CHAPTER VIII

## HINTS ABOUT IMPROVED AERIALS

LET us assume, then, that we have substituted a series of electron tubes, or triodes as we should learn to call them, for the crystal detector, so that our outfit, with its improved inductances and capacities, coupled with its original equipment of high-resistance (2,000 to 3,000 ohm) telephone receivers, is prepared to deal efficiently with even very feeble messages that come from the aerial.

Can we, by way of further perfection, do anything to improve the receptivity of the aerial itself?

The question must probably be answered in the negative, provided you have originally taken reasonable pains in the erection of the aerial that has hitherto served your purpose. If you are a city dweller you probably have not much choice as to how or where the aerial shall be strung. And yet, if you will go to the housetop and look the field over, you may find that there are neglected possibilities in the way of chimney tops or water tanks or what not, by utilizing which you might get a longer stretch of wire or adjust the wire in a different direction.

As to the latter part, remember that you will receive much stronger messages from the direction in which the wire points. If there is some particular broadcasting station at or near the limits of your range to which you would like to listen, you will do well to adjust the wire pointing in the direction of that station, if such an adjustment should prove feasible.

As to the length of wire, it is true that a long stretch gives you relatively wide range; but that is not an

unmodified advantage, as the difficulties of tuning are increased and the possibilities of interference from undesired waves may more than counteract the gain. It is universally admitted now, that for receiving only a single wire is often as satisfactory as a series of wires; and that, as a rule, the wire need not be more than a hundred feet in length, to get optimum results. A much shorter wire will serve the purpose on occasion.

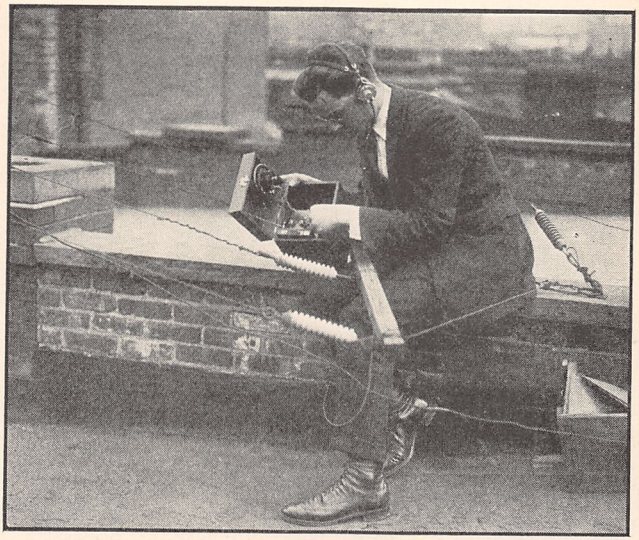
Nor need the aerial be at a great height in order to secure even distant messages. Emphasis has already been laid upon that point, but it will bear repeating. We shall learn that aerials strung along the top of railway cars prove altogether satisfactory; and Mr. Godley's twelve-foot-high aerial, over there in Scotland, to receive the transatlantic signals, will not be forgotten. It should be added, however, that Mr. Godley used an arrangement known as the Beveridge antenna, involving certain complications that we shall examine in another connection.

The question of location of the aerial may be complicated by conditions of local topography. The radio waves, although they pass through obstructions with astounding facility, are not absolutely unaffected by solid structures. A mountain may cut them off altogether; groups of high buildings may to some extent obstruct them; and a woodland may absorb a good deal of their energy.

It is desirable, then, to have the city aerial at the top of a fairly high building, preferably the highest in the neighborhood; and in the country the aerial may best be erected in an open tract, preferably level, away from hills and large groups of trees.

But even if these conditions cannot be met satisfactorily, the aerial may still prove adequately responsive. At worst, the electromagnetic waves have marvelous penetrative power; as proved, for example, by the fact that they have brought messages to a railway train in the

middle of a long tunnel several hundred feet underground, —not, however, messages of such strength as those that were heard the moment the train came out of the tunnel. And of course the fact that messages may be received

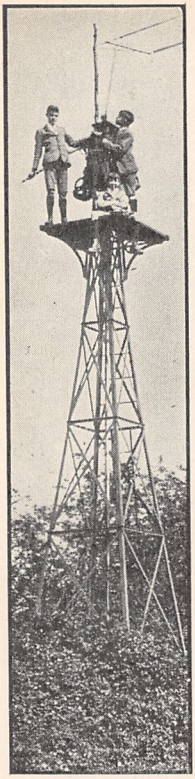


TESTING THE ANTENNA

Here the young amateur has taken a small receiving apparatus to make a local test of the conditions, probably as regards insulation, of the antenna. The photograph gives a very good view of insulators, and of the attachment of the antenna wires to the "spreader." The lead-in wire in the foreground may be followed to the cross-wire, at the extreme left of the picture, which will be seen to connect the four antenna wires, with soldered joints—the latter an important point.

under adverse conditions is no reason why you should not make the conditions the best available.

The suggestions just presented will give you a clue to the ideals at which you are to aim in the erection of an aerial that will give your perfected receiving apparatus the best opportunity to show what it can do.



BOYS USING AN OLD WINDMILL FOR AN ANTENNA SUPPORT

An elementary school at Haslemere, England, has an up-to-date radio equipment and a radio school. Picture shows boys of the radio class making use of the old windmill as the support for their two-strand antenna.

SUBSTITUTE AND MAKESHIFT AERIALS

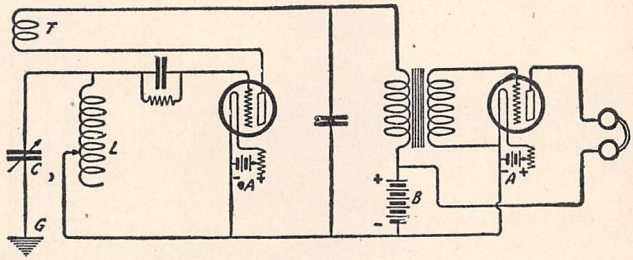
It may be that you are so situated that it is not feasible for you to erect an aerial under even approximately ideal conditions. Conceivably, you may not be able to erect an outdoor aerial at all. Some makeshift must serve your purpose. What then?

Fortunately your case is not hopeless. It would be hard to conceive the position of anyone so situated that he could not install a receiving radio telephone apparatus, of reasonable efficiency; and in particular if you have developed such a receiving outfit as we have just been considering, with efficient tuning apparatus and sensitive amplifying tubes, it will be possible to make a substitute antenna serve quite satisfactorily. Fortunately it happens that the more fully your receiving apparatus is developed, with respect to tuning mechanisms and in particular electron tube detector (and amplifiers), the less it is dependent upon the aerial.

With a highly efficient apparatus, it may even be possible to do away with the aerial altogether. Many radio enthusiasts regard the aerial even now as an obsolescent structure; claiming that the radio receiving apparatus of the near future will be unhampered by the cumber-

some mechanism which has until recently been regarded as essential.

A good measure of support for such a prophecy may be found in present-day experience. We hear, for example, of the report of an amateur radio enthusiast, Mr. Lee Sutherlin, as recorded in the *Wireless Age*. Mr. Sutherlin, of course, uses an improved modern receiving apparatus, with a so-called regenerative circuit that for-




CIRCUIT OF A RECEIVING SET WITHOUT ANTENNA

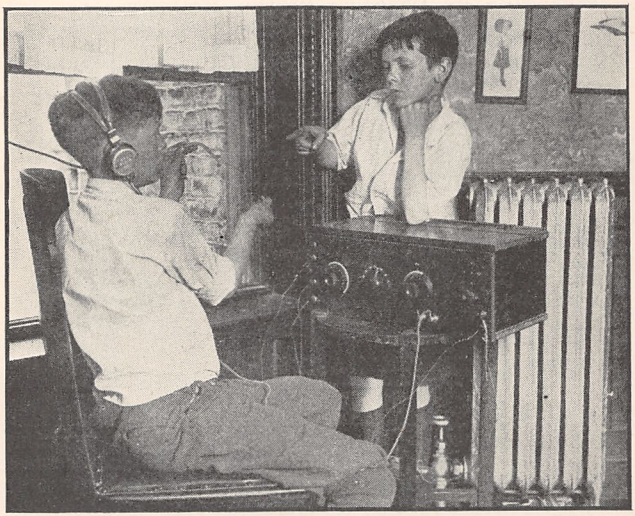
This is the receiver of Mr. Lee Sutherlin, as described in *The Wireless Age*. It will be observed that the "ground," for which the water pipe of a local heating system was used, connects directly with the grid lead, and it may be assumed that the water-pipe system served as a substitute antenna.

tifies the incoming current, and a second electron-tube that further amplifies it. But he uses only a single stage amplification, so his outfit is by no means the most sensitive that could be made. Yet he assures us that he is able to do away with the aerial, and yet to receive messages from distant stations.

"These are the days," says Mr. Sutherlin, "when so many things are being done in radio telegraphy and telephony that most of us are inclined to take much of the new development as a matter of course. If we consider all the minor details of receiving circuits we soon find that there are scores of different ones. The exact

circuit to be used in any one case usually depends upon the apparatus at hand.

"The accompanying diagram shows a circuit which can be made by using a small amount of relatively simple apparatus to be used without an aerial. The value of the



USING A METAL CLOTHES LINE FOR AN ANTENNA

This New York lad, Daniel Callahan, made the double-circuit regenerative receiver himself, but was forbidden by the landlord to erect an antenna on the roof. A clothes-line with wire running through its center served his purpose very well, and the landlord is none the wiser. The other boy, Joseph Early, is young Callahan's associate and coadjutor in the interesting subterfuge.

constants of the circuits are the same as those used in any ordinary short wave receiver with one stage audio amplification. It is not necessary to use separate 'A' batteries as shown. The tuning is accomplished by varying L (inductance) in steps and making fine adjustments with C (variable condenser). The ground employed was the water pipe of a local heating system.

"Using the above circuit, the writer, located just outside of Washington, D. C., was able to hear the concerts sent out by KDKA, the broadcasting station of the Westinghouse Electric & Manufacturing Company, at East Pittsburg, Pa. KDKA was using 650 watts in the antenna. During the past year while located in Pittsburg, Pa., I often heard the high-power stations of the East Coast and Canada with a single tube and without an aerial."

In citing the experience of this accomplished amateur, however, I do not mean to imply that the novice or near-novice can hope to duplicate this feat. I am only fortifying with an illustration the prophecy that the aerial will not always remain a bugbear.

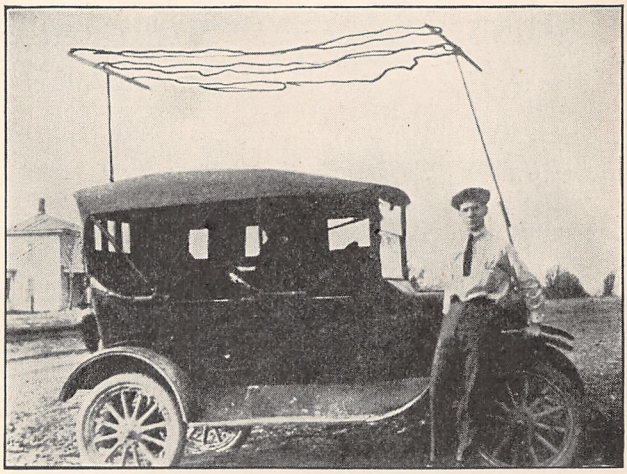
Meantime reference must be made to the experience of other amateurs, some of them mere novices, who have utilized such makeshift aerials as bed springs (in their ordinary location), a metal fire escape, wires strung along the ceiling of a room or from room to room to an interior hallway, the wire of an ordinary call bell running from front to rear of an apartment, and strips of tinfoil pasted against the back of a wall curtain. These and such like isolated mechanisms of electrically conductive metal may serve on occasion, though they are by no means to be recommended as fully adequate substitutes for the conventional out-of-doors aerial.

### THE LOOP AERIAL

I wish in addition to refer, however, to a type of indoor antenna that must be spoken of as a substitute rather than as a makeshift aerial. I mean the device known as the loop aerial.

This extremely simple apparatus consists essentially of a wire such as might be used for making an ordinary aerial, wound about a light frame so that it makes a square loop comprising ten or fifteen turns of wire. The frame is pivoted on the standard so that it can revolve

and thus point the loop in any direction. The ends of the wire are connected to the tuning apparatus of the receiving mechanism, just as in the case of an ordinary aerial; except that it is not necessary to ground the loop.

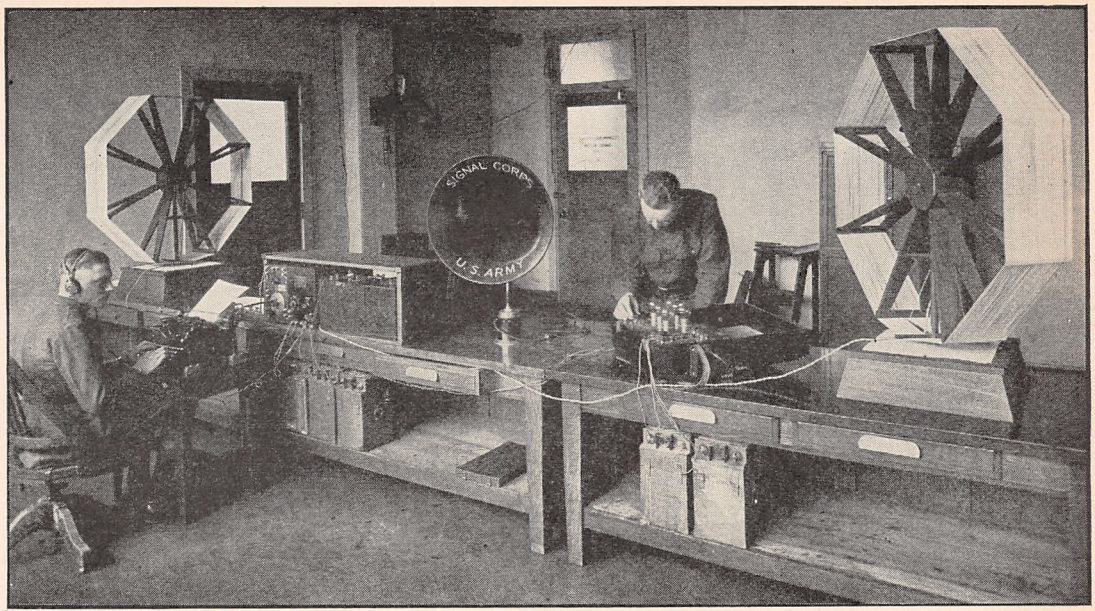


A PORTABLE ANTENNA

This antenna, adjusted on the motor car, is obviously a home-made affair.
But there is at least one company of automobile manufacturers who have put on the market a car equipped with an antenna, somewhat neater than this in appearance, but not different in principle, so that users of the car may "listen in" as they ride. The Newark *Call* equipped a car for both receiving and transmitting, to be used by a reporter. California reports a radio-equipped omnibus. Doubtless the radio-equipped motor car will be a commonplace in the near future.

The entire apparatus may stand on a small table or desk, or it may be suspended from the ceiling. In any event, it is indoors, and its use does away with the bother-ment incident to the erection of whatever type of outdoor aerial.

It should be stated at once, and unequivocally, that

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LOOP-AERIALS USED BY THE U. S. SIGNAL CORPS

Almost any coil of wire, adjusted about a frame that can be rotated on its vertical axis, constitutes a loop aerial. The ones here shown are more elaborate, having an unusual number of turns of wire, and are thus adapted for long distance reception. Even European stations are within range.

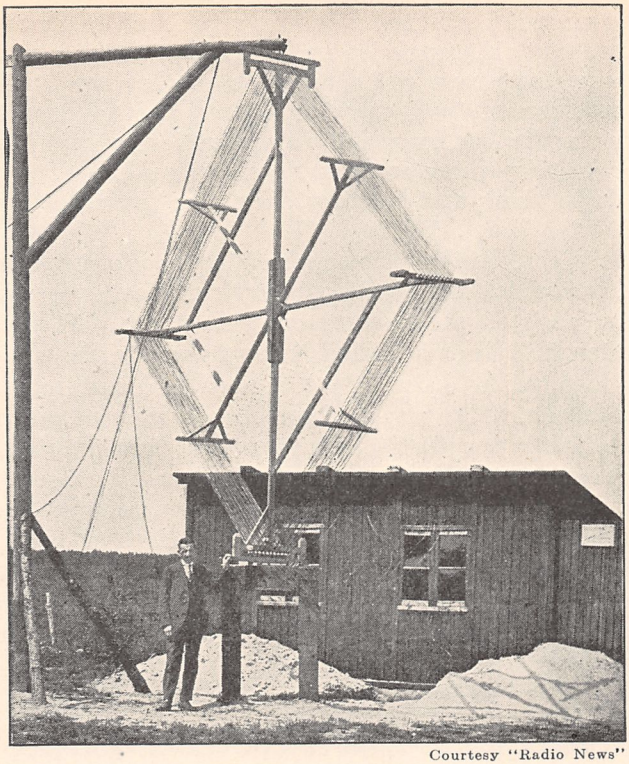
the loop aerial is by no means so sensitive to radio waves as the length of wire with which it is composed would be if stretched out to form an aerial of ordinary type. That goes almost without saying; otherwise everyone would use the loop antenna, and the other form would practically go out of existence.

On the other hand, it must be understood that the loop, even if relatively inferior in sensitiveness, is nevertheless able to operate effectively at long distance if supported by a modern receiving apparatus of good amplifying powers. It would not answer at all with a crystal detector, nor with a single electron-tube detector; but with several of the latter, or even a single amplifier, it may become a very satisfactory medium for the reception of radio waves. Its full possibilities are realized, however, only when the sensitiveness of the receiving apparatus has been further enhanced by the introduction of radio-frequency amplification.

I dwell thus on the loop aerial because I believe that such an apparatus may solve the problem for many would-be radio receiving telephone users who do not mind the expense of up-to-date equipment, but who chance to be so located, in city house or apartment, that the erection of an out-of-door antenna is not feasible, and who have therefore felt that they were barred from using the radio receiver.

It remains to note that the loop aerial has certain inherent qualities that make it, under certain conditions, much more than a mere substitute for the ordinary aerial. I refer in particular to the fact that the loop, as a receiving antenna, has strong directional powers. It responds accurately to the impact of waves coming from the direction in which it is "pointed"; that is to say, waves that flow across the loop line of its major plane, thus striking one edge of the coil before the other.

When the coil is slowly rotated, the signal weakens,



Courtesy "Radio News"

A GIGANTIC LOOP AERIAL WITH DERRICK MOUNTING

The loop aerial is highly directional, so must be arranged to rotate, unless intended for reception from a single transmitting station. The problem of making the loop rotational has here been solved in a simple and effective manner. Such a loop as this, used at a seaside station, serves as a radio compass. By comparing the simultaneous records of two or three different stations located some distance apart along the coast, the position of a ship that has lost its bearings in fog or storm may be accurately determined.

and when it has turned a quarter way round, so that its plane is at right angles to the direction of the on-coming waves, the waves strike all parts of the loop at the same moment, and there is no response whatsoever. Turning the loop horizontally also modifies its sensitivity, particularly in case of a loop wound with all the turns in a single plane; that is to say, the flat or "pancake" type of coil.

It is obvious that this power of the loop to reveal the exact direction of the station from which the messages are received is of exceeding importance. A practical illustration of this was furnished during the war, when a series of loop aerials, operated at various places along the British coast, revealed, through the charting of several directional lines, that a German warship from which unintelligible signals were being sent had changed its location by several miles. The British Admiralty at once concluded that the German fleet contemplated action; and the British fleet was ordered out, and thus actually went in pursuit of the enemy before the enemy had started its maneuvers. The battle of Jutland was the sequel.

### THE RADIO COMPASS

If the loop aerial had done nothing more than that, it would have justified citation as one of the important wartime developments. But in point of fact, the direction-finding apparatus has taken its place as a practical mechanism of every-day utility in time of peace. Under name of the "radio compass," the loop antenna is installed at various stations along the sea coasts, to guide incoming ships that may have lost their bearings in fog or storm.

Three such stations, acting jointly, can determine the location of any ship from which a signal comes, and of

THE HEART OF A RADIO COMPASS

This is a so-called goniometer used in connection with a loop-aerial as a direction finder, or radio compass, on Senator Marconi's yacht. There are various types of radio-compasses, but the same principle applies to all of them. The loop aerial reveals the direction of the transmitting station from which a message comes. The message is loudest when the plane of the loop has an edge pointing toward the stations. As the loop rotates, the message fades. When the loop has rotated through ninety degrees, and is broadside toward the station, the message is extremely faint, or disappears altogether. With the axis of the loop adjusted to a compass, bearings may readily be taken.

course the information may then be sent by radio to the ship itself.

There is, for example, such a station at Montauk Point out at the end of Long Island; and another station at Sandy Hook on the Jersey Coast; and a third station on the Long Island coast about halfway between. Thus these stations simultaneously receive a signal from a ship anywhere within range of their radio apparatuses, their respective loop aerials are pointed until the signal is at a maximum, and the line is charted on a map. Each station immediately radios the information thus gathered, giving the points of the compass, to a central station, where the three chartings are collated, under the simple principle of triangulation.

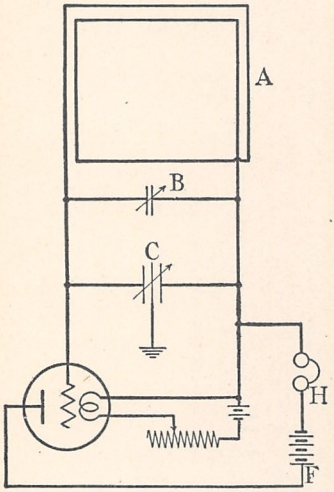



DIAGRAM OF RECEIVING APPARATUS WITH LOOP AERIAL FOR DIRECTION FINDER

It will be seen that the loop itself supplies inductance, so that no additional coil is used. Tuning is accomplished with the variable condenser B. In this instance, a second variable condenser (C) is introduced and grounded. As a rule, no grounding is required with the loop aerial.

The point at which the three lines intercept, somewhere out in the ocean, is of course the point from which the ship has sent the signal.

The captain of the ship, prevented by fog or cloud from making observations, does not know his own location; but the radio compasses on the shore, perhaps a hundred or two hundred miles away, reveal it to him.

Still more recently the successful attempt has been made to install a radio compass on the ship itself. The

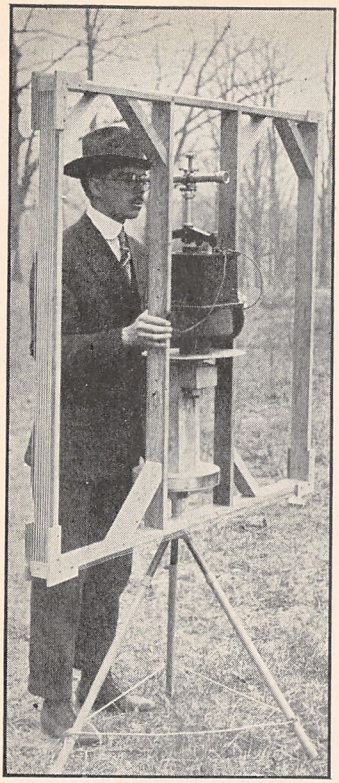
loop aerial is adjusted above the pilot house, and its axis is prolonged into the pilot house and the divided base fixed astride an ordinary compass, in such wise that a

© Ewing Galloway

THE MARCONI RADIO COMPASS IN USE

This shows the direction-finder in use on the steamship *Vauban*. This ship has one of the best radio outfits in the world, enabling it to receive messages from a distance of 11,500 miles, or practically half way round the world. The photograph shows R. Gregg, second wireless operator of the *Vauban*. The direction-finder consists of two loop aerials adjusted at right angles, and with their axes so connected with the goniometer that the operator, while listening in, and adjusting the apparatus in accordance with the varying loudness of the message, makes readings that determine the direction of the transmitting station, and therefore the position of the ship itself. Note the six small ("peanut") triodes that receive and amplify the radio signals.

fine wire stretched across its base revolves with the loop across the face of the compass, and thus shows the navigator at a glance the direction in which the loop is pointing.



Courtesy "Radio Broadcast," N. Y.

A PORTABLE DIRECTION-FINDER

The loop aerial is here adjusted to rotate on a portable stand. A telescope is used to sight the transmitting station, and a circular disc, shown below the hands of the observer, marked like a compass, shows the relative direction of the plane of the loop at any given moment. Tests may thus be made of the direction-finding qualities of the loop.

Lighthouses or lightships along the shore are provided with transmitting radio apparatus, automatically adjusted to send forth a given signal, just as ordinary lighthouses send out flashes of light. Such radio signal stations are known as radio beacons. The navigator using the radio compass can recognize each beacon by the predetermined signal that is continuously sent forth; and by fixing the direction of three such beacons, he can chart his own position with a good measure of accuracy.

### THE LOOP AERIAL ON AIRSHIPS

The interesting and important performance of the radio compass as an aid to the navigation of ships, is matched by another feat of the same implement in which it reveals to the airplane voyager, lost above the clouds or puzzled by the fog, the direction of the land he would seek; otherwise he might fly seaward to his ultimate destruction.

In this case, the loop aerial is on the airship itself, and its use reveals the direction from which the land signals come.

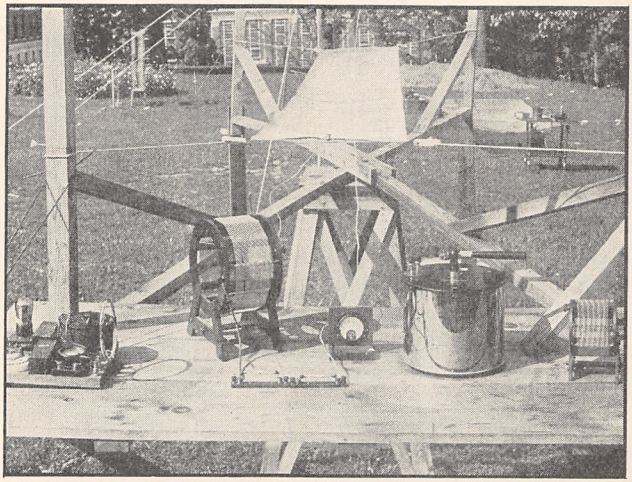
A single signal does not fully serve the purpose, because the loop does not discriminate between a message going in one direction and a message going in exactly the opposite direction. That is to say, it reveals the plane in which the waves are traveling, but not the direction in which they are traveling. If the message is strongest when the loop is pointing, let us say, directly north or south, the message may be coming either from a north-lying station or a south-lying station. So a single signal, say from the Jersey Coast, when the aviator is a hundred miles or so to the east over the ocean, might cause him to point his plane directly away from the signal station instead of toward it. A second signal, however, let us say from Montauk Point or from Fire Island, will enable him to make the right interpretation. His compass has shown him the east-and-west line and the north-and-south line; and there is no longer danger that he will fly seaward instead of landward.

### THE LOOP AND "STATIC"

There is yet one other great merit of the loop aerial in referring to which we come back to the needs of the average amateur. This is based on the fact that the indoor antenna, because of its location, will be free from the influence of those random electromagnetic waves due to atmospheric electricity and which become a veritable bugbear to the radio operator under the name of "static."

You will not long have been a listener at the radio receiving telephone, particularly in the summer season, before you make the acquaintance of "static," and learn that it is your persistent and most annoying enemy. It will cause sundry creakings and croakings and murmurings, as you listen, that will often quite obliterate the

message you desire to hear. When a thunder storm is present or pending, the disturbance due to static will become so pronounced, that use of the radio receiving phone is quite out of the question. Under such conditions, the loop antenna will prove a boon, for it takes



Bureau of Standards Photo.

A NET THAT WILL CATCH MOSQUITOES OR RADIO MESSAGES

Illustrating experiments of the U. S. Signal Corps, in which a strip of ordinary wire mosquito netting was used as an antenna. This was found to have a measure of directional qualities and to act much more efficiently when stretched horizontally, as in the photograph than when tested vertically. One merit of this novel antenna is that it can be rolled up and thus transported even more readily than a loop-aerial.

little note of "static" and may be used under all weather conditions.

Despite its limitations, then, the loop antenna has many things to commend it. It represents a departure from the ponderous out-of-door aerial that in the early day of radio was supposed to be absolutely essential; and

it probably gives augury of a not distant time when the out-of-door aerial, at least in connection with the radio receiving telegraph and telephone, will be obsolete. Probably the loop aerial in its present form will be obsolete also; its place being taken by a mechanism far more compact and in all respects far more efficient in its operations.

### THE LOOP AERIAL FOR EVERYDAY USE

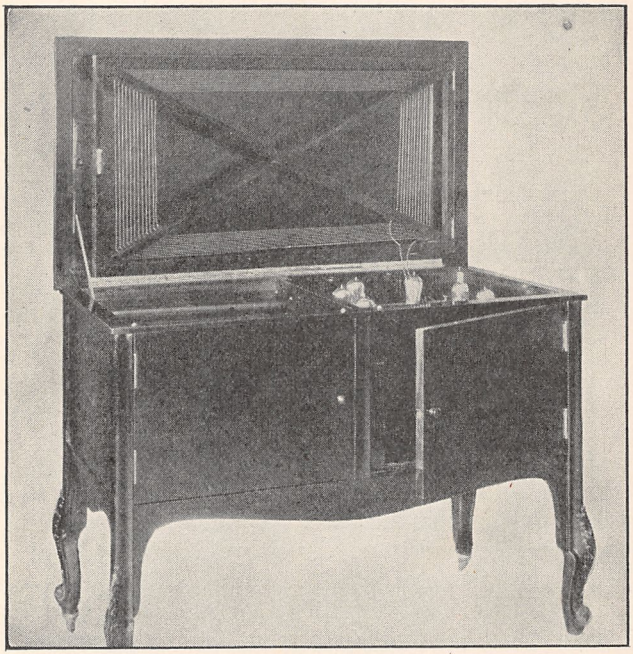
Meantime I wish to refer somewhat more at length to a radio receiving outfit that has been very recently developed, which I have had opportunity to test under the adverse conditions of a city apartment dwelling; in which a loop antenna of the simplest character proves itself an effective and satisfactory receiver of radio messages.

The outfit in question comprises two stages of radio-amplification, a detector tube, and three stages of audio-frequency amplification; but the entire mechanism has been so simplified that any tyro can learn to operate it after a few minutes' inspection.

The hook-up is extremely simple. The little coil itself supplies the only inductance. Tuning is accomplished with a variable condenser. A voltage-divider (commonly called a potentiometer) stabilizes the current of the grid current. Three rheostats modify the three groups of filament current. The two air core and two solid core transformers and the detector-grid condenser (with grid leak) require no attention; although it may be noted parenthetically that the two air core (radio frequency) transformers can be removed at will, being socketed, and substituted with others to aid in modifying the wave length.

The entire apparatus of tubes, condensers, stabilizer, and transformers, is contained in a box less than two feet long by seven and one-half inches wide and eight and a half inches deep; the whole weighing about twenty pounds. The loop aerial which completes the outfit

(aside from the batteries) comprises ten turns of No. 22 cotton wound wire about a wood frame; the finished loop being eighteen inches on a side. The entire apparatus with its standard and axis weighs three pounds.

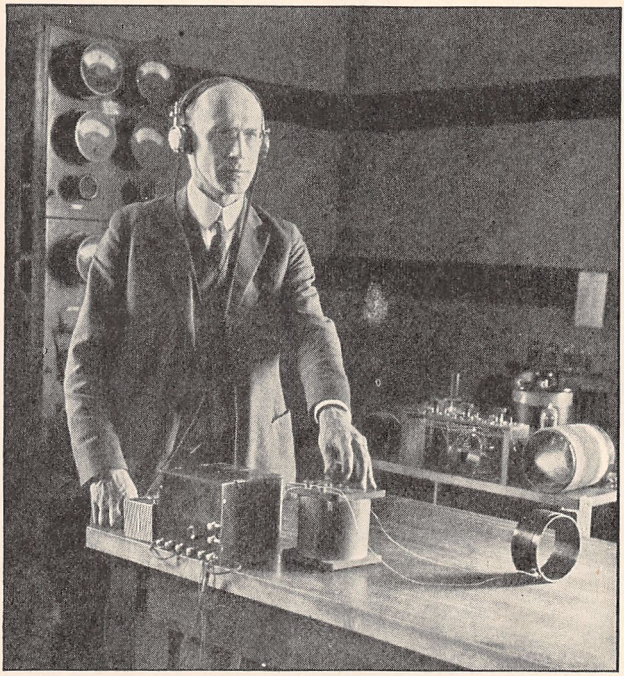


A SELF-CONTAINED RADIO-RECEIVING APPARATUS

This cabinet, made by The Radio Guild, of New York, contains a complete receiving outfit, comprising several stages of both radio- and audio-frequency amplification, with loud speaker and both "A" and "B" batteries. The loop aerial is adjusted in the folding cover of the cabinet in suchwise that it can be swung out on hinges, like a door, to get the direction of any transmitting station. Such self-contained radio-receiving apparatuses, with loop aerial, are sure to gain popularity. It is necessary to use at least two stages of radio-frequency amplification to operate effectively with the small loop, unless the transmitting station is very near or exceptionally powerful.

Even smaller loops may be made. Perhaps the smallest to date is a five-inch coil, used by D. J. M. Miller, of the Bureau of Standards.

The whole outfit, if we overlook the conventional storage battery, is extremely portable. It may be set up and



Courtesy of "Radio News," N. Y.

DR. MILLER OPERATING HIS NEW AMPLIFIER

On the table is the coil used as a loop aerial

adjusted for receiving in two or three minutes' time. In place of the cumbersome out-door aerial, which at best requires a good deal of labor in its construction, we have this single little coil of wire with its standard that may be placed on floor or table, and then revolved on its axis

so that its edge points toward the station from which we wish to receive messages.

The rheostat to adjust the current for the filaments requires but a moment's manipulation; the button for the stabilizer is provisionally turned fully to the left, while we tune in with the variable condenser. Then the stabilizer knob is turned slowly as we listen; after which the condenser may call for slight readjustment. The whole thing is absolutely simple. I have personally seen a novice who had never listened to a radiophone message before, adjust this five-tube radio and audio-amplifier with complete facility at the first effort; shifting at will from a broadcasting program at 360 meters to amateur conversations at 200 meters and back again.

I emphasize this matter of ease of handling because it is commonly supposed that the use of radio-frequency amplification in particular calls for attention of a practised hand. The development of an outfit, in itself simple, in which adjustment has been made so nearly automatic, marks an important stage of progress in the radio art.

## CHAPTER IX

## RADIO-FREQUENCY AMPLIFICATION AND SUPER-REGENERATION

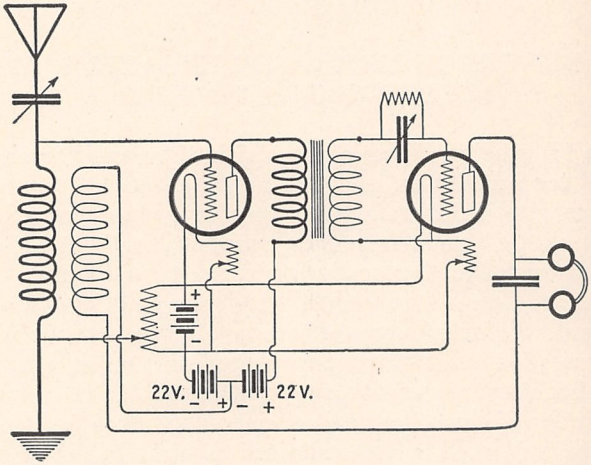
OUR studies of the loop aerial in the preceding chapter brought us in contact with a type of radio-receiver with which we had not previously been concerned. The phrase "radio-frequency amplification" was introduced casually. Naturally our curiosity is aroused.

The radio receiving outfit which we had built up by successive stages, comprising now a detector tube with regenerative circuit and two stages of audio-frequency amplification, represents a type of apparatus that might justly have been characterized, until very recently indeed, as the last word in the radio art as hitherto developed. Yet now it appears that there are certain theoretical possibilities that such an apparatus does not realize, in that the message-bearing current is brought directly to a detector tube, instead of being sent first through one or more amplifying tubes. Certain advantages accrue if the input (radio-frequency) current is amplified before being rectified.

It is true that the input current of our receiver is accentuated or "regenerated" through the influence of the feed-back circuit, and that this constitutes amplification of a very important degree. But might it not be possible to attain amplification of far greater magnitude by using a series of amplifying tubes before bringing the message to the detector tube?

The importance of the suggestion will be more obvious if we reflect for a moment on the essential character of

the action of the detector tube,—reviewing our previous knowledge, and perhaps to some extent amplifying it. We are chiefly concerned, it will be recalled, with the action of the grid in modifying a current represented by




RECEIVER WITH ONE STEP OF RADIO-FREQUENCY AMPLIFICATION

The tube at the left is the amplifier; that at the right a detector. The transformer between the two tubes is of open-core type, to handle the radio-frequency alternating current effectively. The circuit is regenerative because the plate circuit of the detector tube includes the secondary coil (conveniently the rotor of a vario-coupler), which then acts as a tickler coil. Note that the "B" battery is tapped to put 22 volts on the detector, with full voltage on amplifier and transformer. Note also the two rheostats and the stabilizing potentiometer.

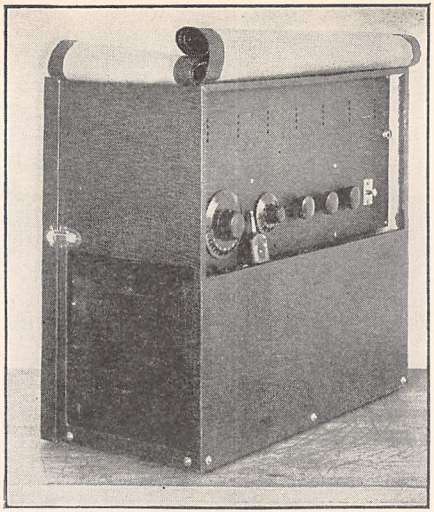
a stream of electrons flowing from the incandescent filament to the cold plate and then circling through the outlying portion of the plate-filament circuit, which includes the "B" battery and the telephones. If the grid were not present, or if it were not electrified, this flow of electrons would be continuous, constituting a direct current. But

the electrified grid, incessantly changing its potential with the oscillations of the input (message-bearing) current, serves to check the flow of electrons during its negative phase and to accentuate the flow during its positive phase.

Such accentuation during one half-cycle and retardation during the other, resulting in a pulsing current in the plate circuit so much stronger in one phase than in the other as to constitute a direct current, represents, as we know, the function of "detection" or rectification of current, without which the plate-filament current cannot affect the telephone.

But it is axiomatic to say that the pulsing current must have a certain amplitude or force in order to make the telephone diaphragm produce an audible response. The object of amplification is not merely to make audible sounds louder, but to bring inaudible pulsations to the grade of audibility. It is readily conceivable that the perfectly equipped radio-receiving apparatus may receive radio messages and pass them on perfectly rectified through the telephones; and that the listener may hear nothing, because the impulse was too feeble to make the telephone diaphragm oscillate vigorously enough to affect the ear drums. This is not merely conceivable; it is the sort of thing that happens incessantly in the case of radio waves that come to every antenna from transmitting stations that lie beyond the range of reception of the particular receiving outfit adjusted to that antenna.

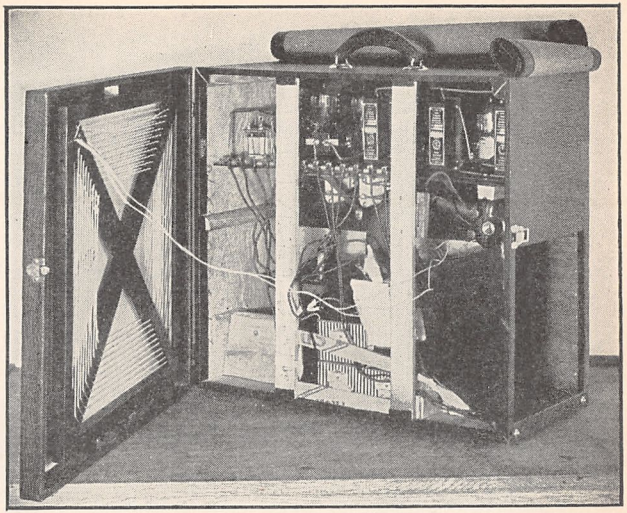
The proof of this, if proof were needed of a proposition so self-evident, is given when we adjust a better type of receiving outfit to the antenna,—as when we substitute a triode for our crystal detector, and so are able to reach fifty or a hundred miles, instead of being limited to fifteen or twenty. The triode did not cause the electromagnetic waves from the hundred-mile station to impinge any more energetically upon the aerial; it merely interpreted the message, where the crystal had failed,



Courtesy Radio Guild, N. Y.

A COMPACT AMPLIFIER IN PORTABLE CASE

This compact outfit, with cabinet, is made by The Radio Guild, of New York City. It comprises three steps of radio-frequency amplification and three of audio-frequency; and is operated with the small loop aerial adjusted within the cover, as shown in the next illustration.



INTERIOR VIEW OF THE COMPACT AMPLIFIER

This shows the portable outfit with the cover open, so that the loop aerial may point in any desired direction. In the upper part of the case are three radio-frequency transformers and corresponding amplifying tubes. Just below, at the left, are two white objects that will be recognized as "Bradleystats," the new type of rheostat. It will be seen that a wooden megaphone, to act as loud speaker, is built into the case. No outside antenna is required.

because it could amplify the feeble current as the crystal detector could not do.

Similarly the feed-back circuit affected further amplification; and then in turn the audi-frequency amplifying tubes added their quota; with the net result that message-bearing currents infinitesimally feeble were brought to the range of audibility.

To speak in more exact terms, we may cite the estimates of the Bureau of Standards experts, who tell us that an ordinary crystal detector can handle a current of 50 microamperes (millionths of an ampere), and that an exceptionally sensitive crystal may be able to handle a current so feeble as ten microamperes; but that the ordinary electron tube with the simple detector circuit rivals the best crystal; that the detector tube containing gas or connected in a regenerative circuit can detect a current of one microampere; and that an oscillating tube operating in a good circuit responds to a current of one-one-hundredth of a microampere,—that is to say, a current one hundred million times more feeble than the current from the local ("A") battery that lights the filament in the triode.

Otherwise stated, the triode under these conditions is 5,000 times more sensitive than an ordinary crystal, and 1,000 times more sensitive than the best crystal. The discrepancy is of course proportionately greater if we consider the triode outfit equipped with additional tubes for audio-frequency amplification. With such an outfit, we deal with quantities of energy that are indeed infinitesimal.

But suppose that we could find a detector that would exceed the triode-detector in sensitiveness as much as the triode exceeds the crystal—what then? Why, obviously, we should then be able to reach out still farther, bringing yet more distant stations within range. Or, stated otherwise, interpreting yet more feeble messages. Or, viewing the matter from another angle, we should be able to get

a much louder response from the station that is already audible; or to receive the message with a much less efficient aerial, as, for example, a small indoor loop. In a word, we should greatly add to the efficiency of our apparatus.

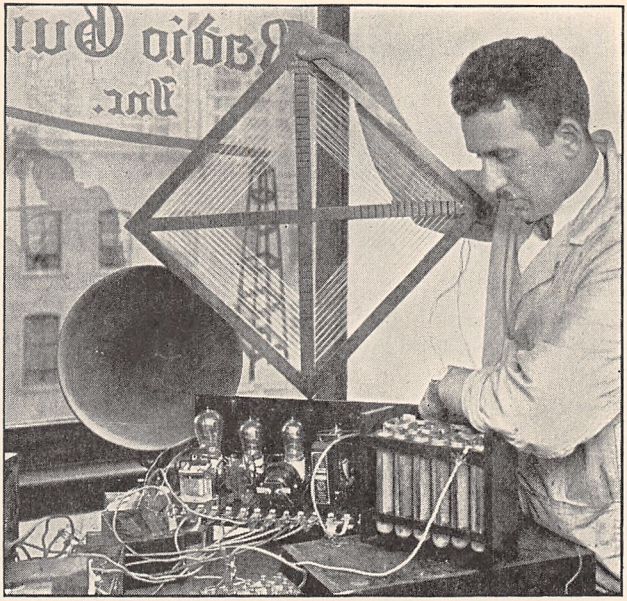
Let me hasten to add that up to the present there is no intimation that any inventor is even on the track of a new type of detector to substitute for the triode. The great advances that have recently been made have not been in the way of developing a new type of detector, but involve only the bringing out of possibilities inherent in the action of the triode itself. And the extraordinary developments in question have been of two types. The first consists of the introduction of one or more triodes to act as so-called radio-frequency amplifiers, accentuating the current before it is brought to the detector. The other, and still more recent development, consists of such manipulation of the input current, with the aid of local batteries and transformers, as to constitute what the inventor of the method, Major Edwin H. Armstrong, terms a super-regenerative circuit.

These two newest methods of increasing the sensitiveness of the radio-receiving outfit must now claim our attention. First we have to do with radio-amplification, including the refinement known as the super-heterodyne method, the latter also due to Major Armstrong.

### RADIO-FREQUENCY AMPLIFICATION

We have seen that a certain amount of amplification of the input current is inherent in the action of the triode detector; and that such amplification is even more conspicuous when a regenerative circuit is used. The message-bearing current that comes to the grid circuit may compare in strength with the filament current it encounters there as 1 compares to 100,000,000. If it were not enormously amplified it could never be recognized.

Obviously such amplification, as exercised by the detector tube, is radio-frequency amplification. That is to



MR. LEO. J. WALLENSTEIN, OF THE RADIO GUILD, NEW YORK, TESTING AN AMPLIFIER WITH LOOP AERIAL

The radio-frequency amplifying tubes are hidden in the photograph by the storage battery. Of the three audiofrequency amplifying tubes, the one at the extreme left is a power tube, to give a very loud record. A radio-frequency transformer and (at the left) two types of audio-frequency transformers are shown. Note the use of temporary clamped connections to facilitate the testing of different circuits.

say, it deals with the oscillating radio current that bears the message from the aerial, and amplifies the oscillations without changing their frequency or essential character.

But when we speak of radio-frequency amplification as

a distinct principle, we of course imply something more than this action of the detector tube. What is practically implied is the introduction of one or more tubes, in the secondary circuit, in the position hitherto occupied by the detector tube, to handle the oscillating input current without rectification,—so that the current that passes out along the plate circuit shall still be an alternating current precisely like the one that came to the grid, save only that its phases are increased in amplitude.

A second and a third amplifying tube may be inserted, constituting respectively two and three stages of radio-amplification; so that the current is enormously increased in energy-content before it comes to the detector. Such amplification of the alternating current may be otherwise stated, by way of explication, as representing enhanced change of voltage between the positive and negative phases. And such change of voltage, as we know, when applied to the grid, is precisely the thing that can modify the flow of electrons in the plate circuit of the detector tube.

So it is readily comprehensible that alternations far too slight to have affected the plate current appreciably (in the auditory sense) had they come directly to the detector, may have been so amplified that they produce a very pronounced effect as they now come to the detector grid from the plate of a second or third radio-amplifying triode.

The principle of action through which a triode amplifies but does not rectify the current, is already familiar to us through study of the audio-frequency amplifying tube. The action of the radio-frequency amplifier is altogether similar. This tube, like the other, must be operated at a middle point of the "characteristic curve," so that the changing voltage of the grid does not make it sufficiently positive to draw a large relative number of electrons from the filament-plate swarm. Meantime the actual voltage, determined by "B" batteries and radio-

frequency transformers, is carried to a high level, as we have seen;—that being, of course, the essential object of the entire procedure.

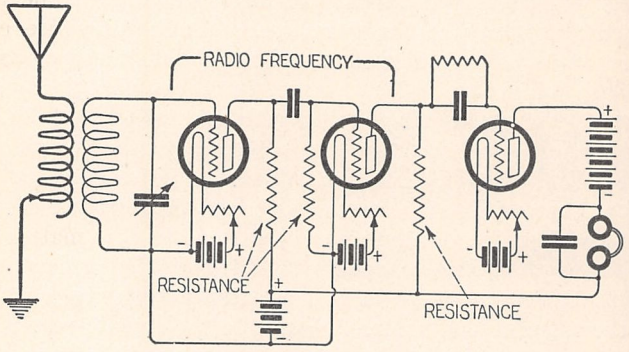
The same type of highly evacuated (hard) triode used for audio-frequency amplification is used to amplify the radio-frequency current. In the latter case, however, there is greater probability of interference from the internal capacity of the tube itself. Some otherwise excellent tubes are not well suited for radio-frequency amplification because of their large internal capacity. Every triode when electrified has a condenser action. This is inevitable, since we have conductors in proximity but not in actual contact. But the tubes may be so constructed that the capacitance is minimized. It is partly because more attention has hitherto been paid to this matter in Europe than in this country, that radio-frequency amplification outfits have had greater popularity on the other side of the water. Thanks to their radio-receiving outfits, a number of British amateurs vied more or less successfully with Mr. Paul F. Godley in receiving American amateur signals, on the occasion of the celebrated transatlantic test in December, 1921. And of course Mr. Godley's phenomenal success was conditioned on expert use of the same principle.

Some of the British amateurs used five or six stages of radio-frequency amplification; and Mr. Godley himself used eight or nine stages, adjusted in a "super-heterodyne" circuit, which we shall have occasion to examine more at length in a moment.

### AMATEUR TRANSATLANTIC RADIO

The outfit having one stage or several stages of radio-frequency amplification may utilize also audio-frequency amplification. An outfit that is rapidly gaining popularity comprises two or three stages of radio-frequency amplification, a detector tube, and two or three stages of

audio-frequency amplification. Until Mr. Armstrong came forward with his super-regenerative circuit, first announced before the Institute of Radio Engineers at a meeting held June 7, 1922, it would have been said that such a combination represented the most sensitive and in some respects the most satisfactory radio-receiving out-




CIRCUIT DIAGRAM OF RADIO RECEIVER WITH TWO STEPS OF RADIO-FREQUENCY AMPLIFICATION AND DETECTOR

In this case there are no transformers, the coupling being accomplished with coils to act as resistances. An outside antenna is used, and therefore a loose-coupler (preferably a vario-coupler) is introduced in the antenna circuit. With a loop aerial, this could be omitted, the loop itself supplying sufficient inductance. The variable condenser in the grid-circuit is an important element in either case.

fit hitherto devised. There were amateurs, however, who would have demurred, claiming that detector tube with regenerative circuit, supplemented by two or three stages of audio-frequency amplification, will accomplish everything that can be asked of a radio-receiving outfit. But the success of the transatlantic test certainly constituted a potent argument in favor of radio-frequency amplification.

All question of divers methods aside, it is worth while

to consider for a moment the feat accomplished by the American amateurs, because it furnishes a vivid illustration of the sensitiveness of the radio-receiving apparatus. Until the thing was actually done, comparatively few experts believed that signals sent from amateur stations, on short wave lengths, could be registered across the ocean. Of course Mr. Godley himself, who went to Scotland to make the test, and the American amateurs who cooperated with him, must have regarded the thing as feasible; but to most others it seemed quixotic. And if we review the conditions, we shall scarcely wonder.

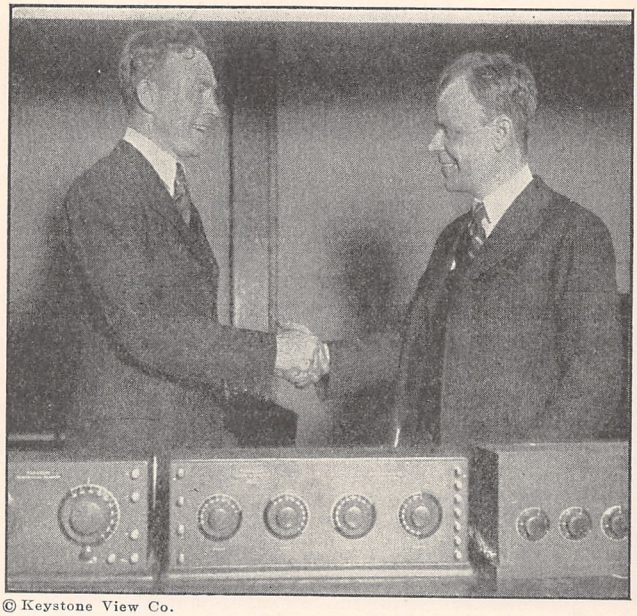
Recall that even the most successful of the American amateur stations that sent the radio telegraph signals was operating with an input power of only 990 watts, and that some of the successful stations used but a small fraction of that power.

Recall, then, that the relatively small amount of energy that actuated the transmitting aerial was distributed among electromagnetic waves that radiated in every direction—toward California no less than toward Scotland; to right and left from pole to pole; and to zenith and nadir with fine lack of discrimination.

Visualize the initial energy being thus distributed, its power decreasing steadily until at the distance of one mile the energy at any given point is attenuated 5,000 times as compared with the energy just after leaving the aerial; and then recall that even that infinitesimal energy would be 3,000 times further attenuated before reaching Mr. Godley's station. (Radio waves appear to weaken directly as the distance, not as the square of the distance. The latter might have been expected, since the law of inverse squares applies to other forms of radiant energy. The departure may be due to the reflection of the radio waves from the upper atmosphere, making them "hug the earth.")

Such figures, of course, can convey no definite impression to our minds; but at least they suffice to give a

vague conception of the feat of regeneration that the little vacuum tubes are called upon to perform in filtering waves of such all but infinite tenuousness out of the



© Keystone View Co.

PAUL F. GODLEY (AT LEFT) AND JACK BINNS

Jack Binns is famous as the wireless operator who stuck to his post and sent wireless messages that brought rescuers to the disabled steamship *Republic*. Paul Godley went to Scotland in December, 1921, to receive short-wave amateur radio telegraph signals across the ocean. Three units of the super-heterodyne receiver with which he accomplished the feat are shown in the photograph.

ether and magnifying them to the proportion of sound-waves that can make audible impression on the relatively sluggish eardrum.

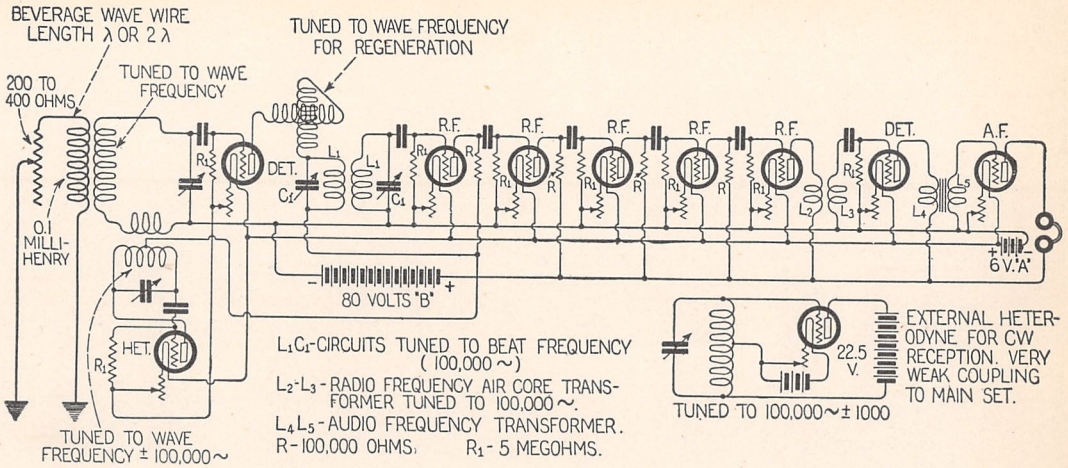
If we consult a diagram showing the "hook-up" of the receiving apparatus that Mr. Godley used in making his

classical transatlantic demonstration, we find that it has many points of familiarity, but there are certain particularities that have not been called to our attention in the examination of the diagrams hitherto presented in this book. It is these particularities that will now chiefly claim our attention in the examination of this highly efficient radio-receiving telegraph apparatus.

It will be understood that Mr. Godley received only telegraph signals (and one full message), but it should be explained that the same apparatus, changed only as to non-essentials, would serve equally well as a telephone receiver; only in that case, since radio telephone messages have a much more restricted range than telegraph messages sent from stations of equal power, the distance between sending and receiving stations must have been far shorter.

We are told that the antenna which Mr. Godley set up there in Scotland was something over 1300 feet long, or approximately the length of two waves of the message-bearing waves that he intended to intercept; and that this wire was erected on twelve-foot poles and was "aimed in the direction of Chicago" in order that the waves might wash along its full length, and thus produce a maximum effect.

Even at that, however, the effect would be far too feeble for detection with an ordinary receiving outfit. It was necessary to use a specially devised receiver, in which the feeble input current was subjected to several stages of radio-frequency amplification before being rectified; and then passed on through two stages of audio-frequency amplification. The particular outfit used by Mr. Godley was an elaborate example of the so-called "super-heterodyne circuit" devised by Major Edwin H. Armstrong, which involves an interesting modification of the principle of radio-amplification. This circuit is so important that we must give it detailed consideration. It will repay careful study.




CIRCUIT DIAGRAM OF THE ARMSTRONG SUPER-HETERODYNE RECEIVER USED BY PAUL F. GODLEY IN THE TRANSATLANTIC TEST

This receiver is fully described in the text. The first detector tube (D E T) operates in connection with the external heterodyne (H E T) to reduce the frequency to about 100,000 oscillations per second. After five steps of radio-frequency amplification, the current is heterodyned to about 1,000 oscillations per second; and then subjected to one stage of audio-frequency amplification. Additional stages of amplification could of course be added. The Beverage wire used as antenna was 1,300 feet long, or about the length of two radio waves. Unlike the ordinary antenna, it was grounded at the distant end, a resistance of 200 to 400 ohms being introduced.

### THE SUPER-HETERODYNE METHOD

One advantage of radio-frequency amplification is that whereas the radio waves themselves are amplified, as is desired, the undesirable invasions of "static" and sundry other lower-frequency currents are minimized, inasmuch as they are not correspondingly amplified. But unfortunately this advantage is more or less negatived by the fact that the current may be invaded by unwelcome oscillations of high frequency,—due sometimes even to such an unavoidable cause as a defect in the tungsten filament, through which electrons are thrown off unevenly,—that are amplified along with the legitimate radio-frequency vibrations, being ultimately productive of utterly disconcerting noises.

To meet this difficulty, and in general to add to the efficiency of the receiver, Major Armstrong devised the modification of the heterodyne method to which the name super-heterodyne has been given.

The heterodyne or "beat" method of reception, it will be recalled, consists essentially of producing with a local tube associated with the receiving apparatus, a high-frequency oscillation that varies in rate from the frequency of the input current by only one or two thousand vibrations per second; with the result that the two currents neutralize each other as regards all oscillations but the residual one thousand or two thousand, the remaining current thus being of audio-frequency. The modification employed in the super-heterodyne method consists in having the local current vary from the input current not by one thousand or two thousand oscillations merely, but by fifty thousand or one hundred thousand, so that the residual current is still of radio frequency, though relatively slow of oscillation as compared with the original current.

There are practical advantages in handling such a current, which can be sent through several or many ampli-

fication tubes (Mr. Godley's apparatus used nine all told) before being rectified.

A relatively simple example of the Armstrong super-heterodyne, utilizing only three amplification tubes, is here shown in circuit-diagram. It will be seen that the first tube is represented as operating on the autodyne principle to reduce the frequency from the original antenna circuit frequency, whatever it may have been, to 50,000 cycles per second.

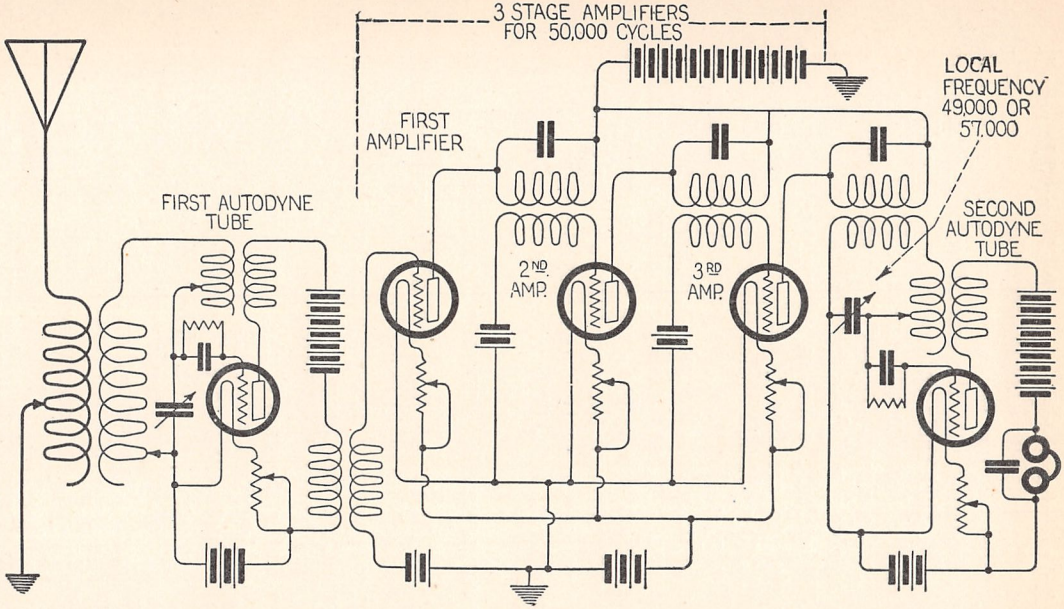
This is still radio-frequency, far beyond the sound-producing limit. At this frequency, the current is passed on, inductively, to the first amplifying tube, and then to the second and the third in sequence, always by way of air-core transformers instead of the iron-core trans- used in audio-frequency amplification.

The use of the induction coil constitutes an "induction-repeating" amplifier in contradistinction to a "transformer-repeating" amplifier. In this case as in the other, however, there is a variable resistance in the grid-filament circuit.

There is a type of amplifier, less generally used, called a "resistance-repeating" amplifier, in which both transformers and induction coils between the tubes are dispensed with. The resistance coupling was used, as will be seen, in Mr. Godley's super-heterodyne, and it is employed effectively in at least one very high-grade audio-frequency amplifying radio receiver now on the market,—an apparatus that is operated by the turn of a single lever.

In Major Armstrong's three-stage amplifier, the fortified current, coming still at 50,000 cycles from the third amplifying tube, is passed on inductively to a second autodyne tube (the fifth and final tube of the mechanism), where a local frequency of alternation of either 49,000 or 51,000 cycles is employed to reduce the amplified 50,000-cycle current to audio-frequency of 1,000.

It is said that this three-stage amplifier with double autodyne reduction is relatively easy to operate, notwith-




A SLIGHTLY DIFFERENT TYPE OF ARMSTRONG SUPER-HETERODYNE RECEIVER

Essentially the same in prineiple with the super-heterodyne shown in the preceding figure, this differs in certain details. The heterodyne effect is produced without the use of an external oscillating tube (this method being known as self-heterodyne, or autodyne), and the radio-frequency amplifiers are connected with transformers (induction coupling) instead of with resistances. In the circuit shown, no audio-frequency amplifiers are used, but these might readily be introduced by hooking up at the point where the telephone receivers are shown.

standing its seeming complexity. Professor Morecroft, speaking of the relative ease of operation of this Armstrong amplifier, points out that the inductances and capacities (condensers) in the second autodyne tube are fixed, and notes that their values are originally adjusted so that when the electromotive forces of 50,000 cycles are introduced in the circuit ($L_2 - C_2$) by the amplifier, the telephone receivers will be subjected to a rectified current of 1,000 cycles, the last autodyne tube being definitely adjusted to oscillate at a frequency, as already noted, of 49,000 or 51,000 cycles per second.

"The only operation that the operator needs to perform, then, is to adjust the receiving inductance $L_1$ and receiving capacity $C_1$ so that the signal may be heard in the phones; when this is the case the frequency of the current passing through the amplifier is either 50,000 or 48,000 cycles (assuming that the last autodyne tube is adjusted to operate at 49,000 cycles per second)."

### AMPLIFICATION WITHOUT DISTORTION

The extraordinary amplification of the current, with the ultimate result of making a feeble message distinctly audible, or even loud, is brought about, as we have seen, by supplementing the incoming current with a current of high voltage from a local battery.

A glance at the diagram of the Armstrong three-stage amplifier just described will remind us that the new current is fed inductively into the grid-filament circuit of each tube from local batteries. The arrangement is such that in the case of each successive tube the voltage of the current thus applied is greater than the voltage of the current applied to the preceding tube. In case of the first tube, the local current accentuates the inductive input current from the aerial.

It may seem strange that fresh accessions of current at higher and higher voltage can thus be intermingled with

the essential message-bearing current from the aerial, to give it ever-increasing force, without interfering with the specific characteristics by virtue of which that current conveys a particular message to the telephone receivers;

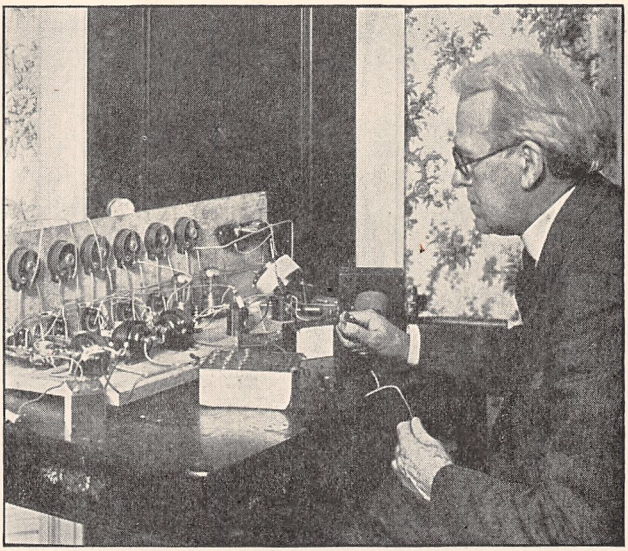


Photo. by Brown Bros., New York

MAKING AN EXPERIMENTAL AMPLIFYING RADIO-RECEIVER

Two steps of radio-frequency amplification and three steps of audio-frequency are being introduced. The set can be made regenerative by hooking up the rotar of a vario-coupler into the detector plate circuit. The round objects at the top of the apparatus are potentiometers, to permit the experiment of putting a voltage bias on the grid of each tube. In ordinary practical sets of similar type, a single potentiometer suffices.

doubly strange, when we reflect that the oscillations of that current have been modified from, let us say, a million cycles per second, first to 50,000 cycles and then to 1,000 pulsations per second. But such is the familiarly observed fact.

The current that comes from the plate of the second autodyne tube (the final tube of the series) to the telephone receivers, enormously enhanced in voltage and therefore in power, but oscillating only 1,000 times per second, a desirable audio-frequency, represents precisely the same modulations that characterize the feeble current oscillating a million times per second that entered the grid of the first autodyne tube at the other end of the receiving apparatus.

Different as they are, in strength and in period, these two currents are identical in the essential quality of representing accurately the modulations of the series of electromagnetic waves that came through space from the transmitting to the receiving aerial; and these modulations, as we know, represent in turn with utmost fidelity modulations of a voice impressed on the diaphragm of the transmitting telephone and conveyed by electric circuits various and sundry to the transmitting antenna.

The whole thing is weird, fantastic, unbelievable; yet it is demonstrably true—a matter of everyday experience in the operation of radio telephone receivers.

### MILLION-FOLD AMPLIFICATION

Dr. De Forest has been quoted to the effect that there is no lower limit of audibility for the audion detector; the implication being that a set of amplifying tubes, properly utilized, might magnify the feeblest conceivable sound to the grade of audibility. The justification for such an expectation is found in the authoritative estimate previously cited to the effect that the grid input power may be amplified 10,000 times in a single detector tube.

Leaps so stupendous appear to be made by very feeble currents only. But Professor Morecroft presents a simple formula showing how the voltage may increase at geometrical ratio from one amplifier tube to another, so

that if the potential of the second tube is ten times that of the first, a third tube would magnify in such proportion as to make the voltage forty-nine times that of the first; while a fifth tube would raise the voltage to 3,400 times the original input; and a seventh tube in series would represent a voltage 118,000 times that of the first one.

It is comprehensible that a very feeble whisper when amplified 118,000 times would become a fairly tempestuous sound.

And of course seven amplifying tubes in series by no means represent the ultimate stages possible. Nor does the ratio of seven to one necessarily represent a maximum difference between tubes. Mr. Earl C. Hanson, the inventor of the vactuphone, a sound amplifier designed to remedy deafness, the action of which depends upon a small vacuum tube, suggests that a ratio of ten to one is not unusual; pointing out that on that basis the placing of six amplifying tubes in series would result in a million-fold amplification.

It will readily be understood, on the other hand, that practical difficulties in the radio-receiving mechanism may increase alarmingly as the tubes are multipled. It must be recalled also that extraneous sounds, mingled with the desired message, may be amplified in like proportion. Mention was made, it will be recalled, of disturbances that might result from almost inconceivably minute variations in the rate or regularity of discharge of electrons from a filament having some infinitesimal flaw in its structure.

These are complicating factors. But it was noted also that amplification at radio-frequency might eliminate certain disturbances, such as those due to the relatively slow oscillations of "static"; also that excessively minute disturbances which would be a source of trouble in radio-frequency amplification may be ignored by tubes exercising the function of audio-frequency amplification.

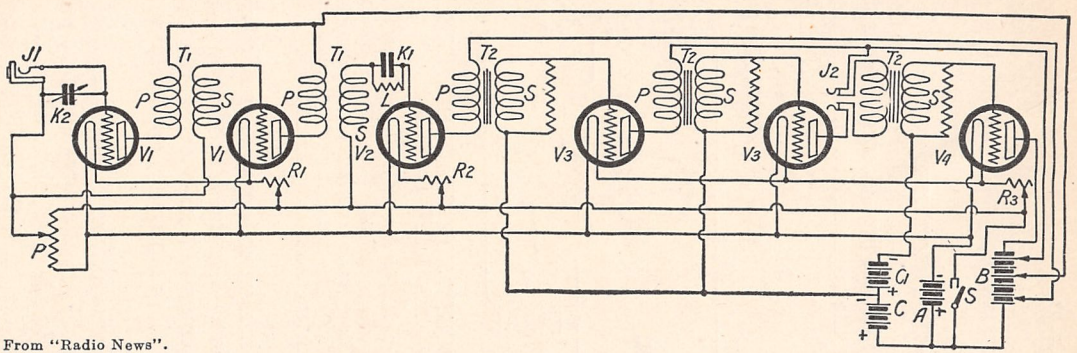
Complications aside, it is feasible in practise for even the moderately adept amateur to use two or three stages of audio-frequency amplification; or to use three stages of modified radio-frequency amplification, as in the Armstrong circuit just studied.

And with the newer types of transformers, especially made to handle the high-frequency current, it is possible to make a receiver using two or three stages of radio-frequency amplification unmodified; followed by a detector and two or three stages of audio-frequency amplification. All the tubes used in this apparatus may be "hard" tubes of the same type. It is especially desirable, however, that the tubes used for radio-frequency amplification should be of low internal capacitance.

The accompanying hook-up will show how we may introduce such radio-frequency amplifying tubes into the circuit of the audio-frequency apparatus already constructed. The advantages that will accrue will consist in giving further sensitiveness to our outfit, so that its range is enhanced and the volume of sound given out by the loud speaker is magnified. So great is the improvement in sensitiveness, indeed, that we may now do away with the outside aerial, if we choose, and substitute a small loop antenna, no more than eighteen inches in diameter, made by winding a few turns of silk-covered or enameled wire (No. 22 or thereabouts) around a light wooden frame.

With such an antenna, the loop itself supplies sufficient inductance, and the loose coupler or its equivalent may be dispensed with. We bring the ends of the loop-wire into the circuit as if they were end wires of a secondary coil—linked with grid and filament respectively. No "ground" connection is required.

A voltage-divider, or so called potentiometer (sometimes spoken of as a "stabilizer"), is used to regulate the voltage on the grids, so that the tubes are operated at the right part of the characteristic curve. But the tuning




From "Radio News".

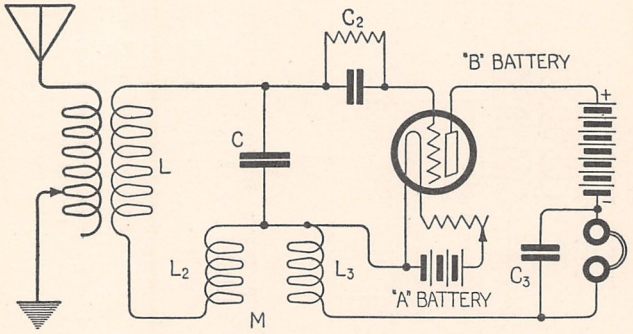
## HOOK-UP OF AN AMPLIFYING OUTFIT WITH TWO STEPS OF RADIO-FREQUENCY AMPLIFICATION AND THREE OF AUDIO-FREQUENCY

This is a practical circuit of very satisfactory character, with loop aerial. It may of course be used with outside antenna if desired, but in that case an additional inductance should be introduced in the input circuit, plugged into jack ($J_1$). The second Jack ($J_2$) receives the plug for telephone or loud speaker. Note that a single potentiometer (P) is employed, and that there is one rheostat ($R_1$) for the two audio-frequency tubes, a second rheostat ($R_2$) for the detector tubes, and a third rheostat ($R_3$) for the three radio-frequency tubes. Two bias batteries (C and $C_1$) are introduced in the grid circuit of the audio-frequency amplifiers. These are linked in series, and also in series with the "B" battery. A single battery with taps would serve the same purpose.

is done with a single variable condenser, shunted across the input circuit, and it is so simple that the veriest novice can operate the apparatus.

### A SINGLE-TUBE AMPLIFIER

The radio-receiving apparatus just described operates without the use of either the regenerative or the hetero-




REGENERATIVE CIRCUIT FOR SIMULTANEOUS AMPLIFYING AND RECTIFYING

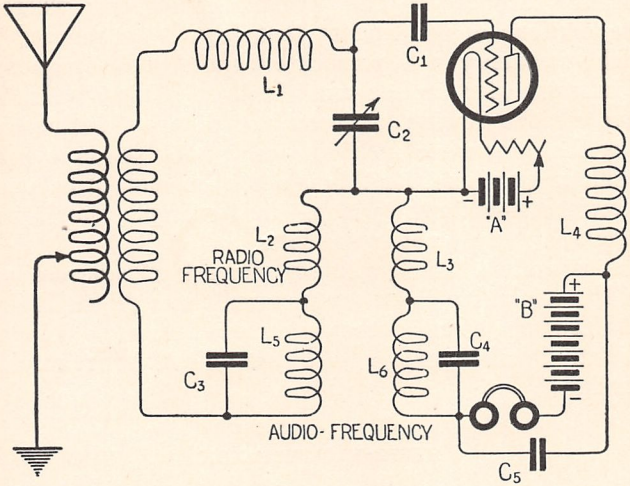
This is an experimental circuit developed by the Bureau of Standard experts, in which additional coils ($L_2$ $L_3$) are hooked with the usual circuits. These coils constitute an open-core transformer, and have to do with the radio-frequency component of the current. Compare with the succeeding figure.

dyne principle. It thus has advantages of simplicity of construction and operation. On the other hand, it involves the use of numerous tubes, sharing this disadvantage with most of the amplifying outfits hitherto constructed.

It has for some time been apparent, however, that it may be possible, by modified use of the regenerative principle, to utilize a single triode in various capacities in the same apparatus. The fact that the simplest detector triode in the ordinary circuit has amplifying power, and

that such amplification is accentuated by the use of the tickler coil that feeds back energy from the local battery, pointed the way to an extension of the principle.

The experts of the United States Bureau of Standards have shown that a single electron tube can be used to




COMBINATION OF RADIO- AND AUDIO-FREQUENCY AMPLIFICATION, WITH DETECTION, IN ONE TUBE

This is another experimental circuit perfected by the Bureau of Standards experts. It is obviously too complicated to be of interest except to the advanced amateur. In the plate circuit, the radio-frequency component of current flows through $L_4$ $C_5$ $C_4$ and $L_3$; while the audio-frequency component flows through $L_4$, "B" battery, telephone, $L_6$ and $L_3$. Compare with the Armstrong super-regenerative circuits to be shown later.

amplify and detect radio-frequency current and simultaneously to amplify the telephone pulses of audio-frequency. A circuit diagram here reproduced shows how this may be accomplished. It will repay careful study.

In effect we have a series of triodes with interlinking radio-frequency and audio-frequency transformers; but in reality one triode takes the place of several, handling

the different types of current that come to it through transformers directly linked in series. The arrangement is such that the input current of radio frequency, as well as the radio-frequency remnant of the current in the plate circuit, may be shunted round the audio-frequency transformers through by-path variable condensers; whereas the portions of the current that have been reduced to audio-frequency will pass through the audio-frequency transformer for further amplification. This apparently involves the flowing of current of different frequencies over the same wires simultaneously; but there is no contradistinction here, for this is a phenomenon of common experience,—without which, for example, multiplex telegraphy would not be feasible.

It is said that the audibility of weak signals received by this method is about one hundred times the audibility attained with a single tube connected in a simple detector circuit. On stronger signals the amplification is relatively smaller.

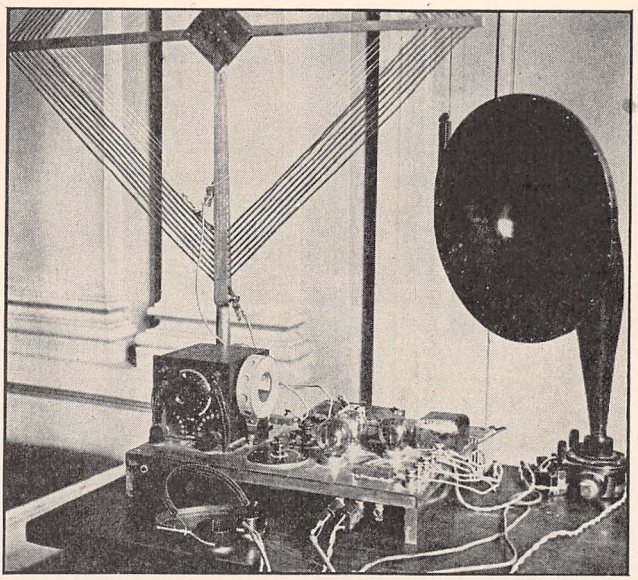
### SUPER-REGENERATION

Such an apparatus seems remarkable enough, but the amount of amplification secured is small indeed compared with what is attained when an additional tube is introduced, and the two tubes (sometimes with a third added) are hooked up in such a way as to combine effects. This is done in the elaborate circuits of the "super-regenerative" apparatus devised by Major E. H. Armstrong, and first announced in detail by him in the paper before the Institute of Radio Engineers, already referred to.

In an address before the Radio Club of America, June 29, 1922, Major Armstrong gave full details of the new apparatus, exhibiting different hook-ups that use one, two, and three tubes respectively. He stated that with three tubes the amplification is one hundred thousand times that of any previous combination of a similar

number of tubes; and in case of telgraph signals, it may reach a million-fold amplification.

Such an estimate conveys no very definite impression to the layman; but the statement that when music and



© Ewing Galloway.

MAJOR ARMSTRONG'S SUPER-REGENERATIVE RECEIVER WITH THREE TUBES

This is the apparatus with which Major Armstrong made his demonstrations of the super-regenerative circuit before the Institute of Radio Engineers and The Radio Club of America, in June, 1922. The three tubes are made to do the work of eight or nine tubes of the super-heterodyne receiver.

speech were only faintly audible in the telephones adjusted to a standard outfit with regenerative detector and two stages of audio-frequency amplification, the super-regenerative apparatus trumpeted them throughout the hall, gives a tangible impression of the discrepancy

implied. Even a single tube made the messages audible; and two tubes gave loud reproduction throughout the auditorium.

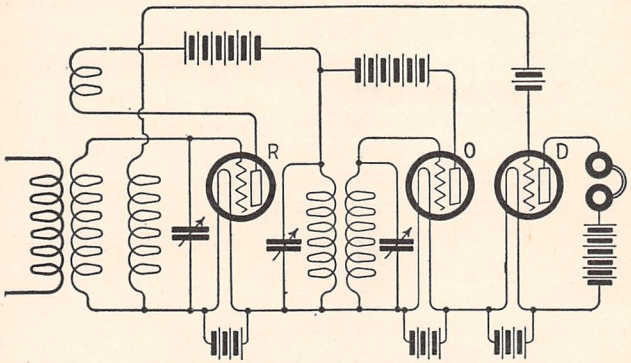
Even without a loud speaker, the ordinary telephone receivers gave out sounds that could be heard throughout the hall.

Peculiar interest attaches to the statement that the degree of amplification is far greater with short wave lengths than with long ones. Indeed, the law of inverse squares appears to hold; so that a message on one-hundred-meter waves is amplified four times as much as a message on two-hundred-meter waves; and if the wave length is reduced to fifty meters, the amplification is sixteen times as great as with the 200-meter wave. In other words, the circuit is peculiarly adapted to deal with short wave-lengths; or, otherwise stated, with high-frequency current. It is reported that Major Armstrong has operated with waves of only fifty meters (representing a current of six million oscillations per second), and it has been suggested that this is by no means the available limit. Indeed, it has been declared that it will be possible in the immediate future to handle wave lengths of only ten meters, or even less; and discrimination, on the part of the transmitting and receiving apparatus, between short waves differing only a single meter in length will be altogether practical.

Justification for the latter prophecy is found in the consideration that, as between ten-meter waves and eleven-meter waves, for example, there is a difference of 2,727,000 cycles of the generating radio current. Obviously, when such discrepancies are in question, there is opportunity for a selective tuning that does not obtain when long waves, generated by relatively low-frequency current, are employed.

Between a 1000-meter wave and an 1100-meter wave, for instance, there is a difference of only 27,274 cycles in the frequency of the generating current. That is to say,

it is (theoretically) one hundred times as easy to tune for one-meter wave changes in 10-meter waves as for 100-meter changes in 1000-meter waves. Otherwise stated, you can (theoretically) tune for *one-centimeter* changes in 10-meter waves as readily as for 100-meter changes in the 1000-meter waves.




ONE OF THE ARMSTRONG SUPER-REGENERATIVE CIRCUITS

Here one tube acts as radio-frequency amplifier, a second as oscillator, to impose a super-audible frequency (perhaps 20,000 cycles); and the third as detector. Note that the plate circuits of the first two tubes are connected; and that the grid of the third tube is in a circuit inductively related to the secondary coil, which in turn is inductively related to the feed-back from the plate circuit of the other tubes. Compare subsequent diagrams showing other super-regenerative circuits.

### ANALYSIS OF THE SUPER-REGENERATIVE CIRCUIT

Examination of the super-regenerative circuits (several are suggested) shows that they represent a logical extension of the original Armstrong regenerative principle. In the introduction of this remarkable apparatus, Major Armstrong has not so much designed a new circuit as amplified and perfected circuits to utilize more effectively the original feed-back principle that made him

famous. Beginning years ago with a single tube and with a single inductance constituting the tickler, the investigator proceeded through the use of series of tubes and modified circuits to develop a super-heterodyne apparatus; then—passing finally from the complex to the simple, as a highly developed art almost always does—he has now produced a condensed super-regenerative apparatus, in which three tubes develop a measure of efficiency comparable to that previously attained with a series of nine tubes.

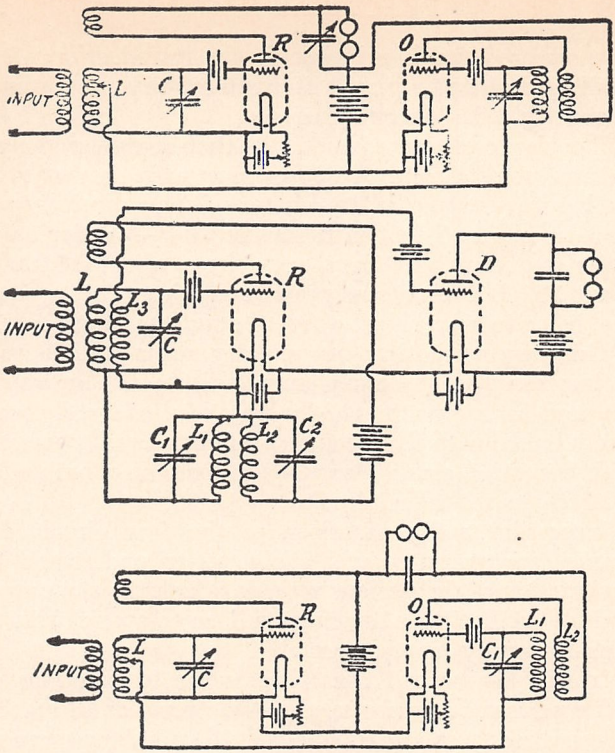
No new apparatus is involved. The super-regenerative outfit employs the familiar triodes (only hard tubes being used) and inductances and condensers; with "A" and "B" batteries, the latter ranging up to 200 volts. The novelty consists merely in the way in which these materials are utilized.

The first thing that strikes the sophisticated observer of any one of the new hook-ups is that its basis is the familiar original regenerative circuit with "feed-back" effected through a tickler coil in the plate circuit. But inductances and condensers are introduced in unexpected combinations.

Details aside, what Major Armstrong has aimed to effect is the bringing out of the full possibilities of the triode as an amplifier. He points out that, under ordinary conditions of regeneration, there is a more or less gradual mounting of amplification, as the feed-back circuit reacts on the input and this in turn reacts on the plate current; but that there comes a time—just short of the stage when the operator feels that his fullest expectations are to be realized—when disruption occurs, so to speak, and nothing more can be gained.

This represents a point at which, in technical phrasing, there is a balance between positive and negative resistances; and, theoretically, no further amplification is possible, as the current is "damped."

But now enters the new principle of super-regeneration.




VARIOUS METHODS BY WHICH MAJOR ARMSTRONG OBTAINED SUPER-REGENERATION

These figures were published in the N. Y. *Tribune,* in the department edited by Jack Binns, with the following caption: "The upper diagram illustrates the manner in which the variation is introduced into the positive resistance of the tuned circuit. This is done by means of an oscillating tube O, the grid of which is connected through the tuned circuit LC of the amplifying tube R.

"The middle diagram illustrates the manner in which simultaneous variation in both positive and negative resistances is obtained. This is accomplished by providing the amplifying tube R with a second feed back circuit $L_1 C_1$ and $L_2 C_2$, adjusted to oscillate at some lower frequency.

"The lower diagram shows how the oscillating tube is made to perform the function of a detector also."

Further details and constants are shown in a subsequent figure.

The essence of this principle is the introduction of an oscillation of a new period, to impress itself on the input current that is being regenerated.

This new oscillation is not, like that of the heterodyne method, something that approximates the frequency of the input current. On the contrary, it is a carefully regulated oscillation that is relatively slow—not far above audio-frequency. It may vary from about 12,000 to about 20,000 alternations per second; the point, in practise, being to keep it just above the range of audibility.

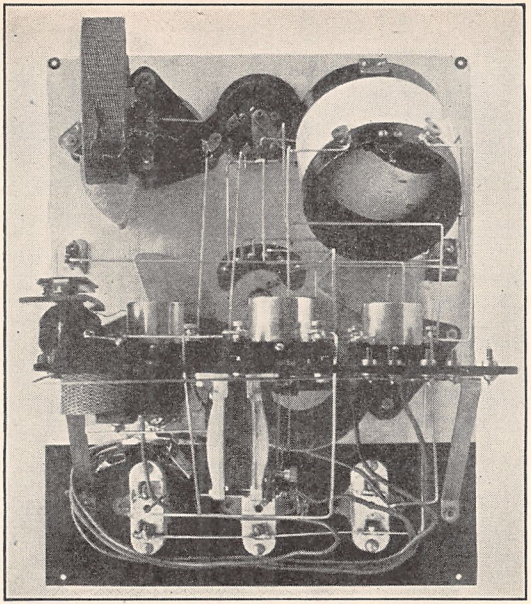
This new oscillation, but slightly super-audible, may be impressed on the input current either (1) by way of the feed-back circuit; (2) by way of a new coil inductively linked with the secondary coil but directly in series with the third circuit; or (3) by combining both these methods in the same circuit.

Inspection and comparison of the four circuit diagrams here presented will enable us to understand the explanation of the various ways in which the slow super-audible oscillation is amalgamated, so to speak, with the high-frequency input current.

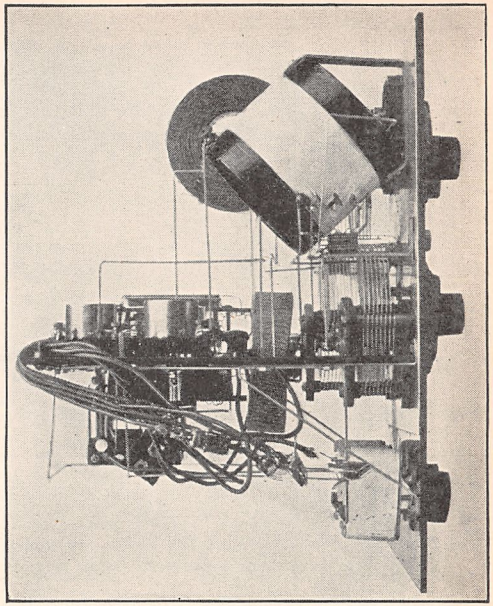
It will be recalled that three separate functions are being performed by the triodes,—the function of amplification directly and as enhanced by the familiar regenerative (feed-back) circuit; the function of oscillation at a frequency determined by the local balance of inductance and capacitance; and the function of detection or rectification to make the current usable in the telephone circuit. These three functions may be apportioned to separate tubes; or they may be performed by two tubes, one of which acts as both amplifier and detector; or all three functions may be performed by the same tube.

Major Armstrong states that the most satisfactory circuit, and that easiest to operate, is the one in which three tubes are used; but the single tube can be made to function with altogether extraordinary efficiency.

With the function of the tube as detector and as ampli-



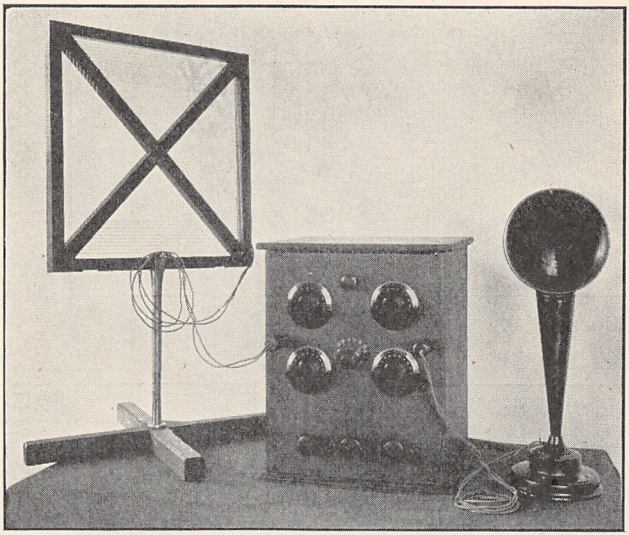
VIEW FROM ABOVE OF AN ARMSTRONG SUPER-REGENERATIVE RECEIVER, WITH THREE TUBES, MADE BY KENNETH HARKNESS, OF THE RADIO GUILD, NEW YORK



ANOTHER VIEW OF THE SAME SUPER-REGENERATIVE APPARATUS

The apparatus, notwithstanding its compactness, has extraordinary efficiency.

fier, we are already familiar. The function of oscillation has been referred to several times, but will come up for more careful consideration when we take up the study of the transmitting radiophone. Here it suffices to state that any triode in a circuit having inductance and capacity



EXTERIOR VIEW OF ARMSTRONG'S SUPER-REGENERATIVE RECEIVER MADE BY MR. HARKNESS, OF THE RADIO GUILD

The message received on the little loop is trumpeted out by the loud speaker with a volume of sound that no one would have thought obtainable from three tubes until Major Armstrong made his demonstration.

(a so-called oscillating circuit) can be made to set up oscillations of definite frequency in the current passing through it. This is done, as we know, when the heterodyne effect is utilized. In that case, as we have seen, the oscillating triode produces a local current of a frequency approaching that of the input current; the two currents

coalescing and neutralizing all but the residual number of phases, so that the remaining current is either (1) of audible frequency, as with the usual heterodyne receiver; or (2) of relatively low super-audible frequency—for example, 50,000 cycles—as in the super-heterodyne which we have examined.

The function of oscillation in the new super-regenerative circuit now under consideration is superinduced in the triode by the influence of a "B" battery in connection with a local coil and capacitance, just as if heterodyne action were contemplated; the difference being, however, that the new principle calls for relatively slow oscillations, instead of the exceedingly rapid ones used in accomplishing the heterodyne effect.

Specifically, as we know, if 200-meter waves are in question, the input current will be alternating at 1,500,000 cycles per second; and the heterodyne current will be made to alternate, say, at 1,499,000 cycles for the ordinary effect; or at perhaps 1,450,000 cycles for the super-heterodyne effect. But in the present super-regenerative circuit, the tube will oscillate at, let us say, 20,000 cycles per second; a pulsation that is sluggish indeed in comparison with the 1,500,000-cycle current with which it is to intermingle.

In effect, then, the new oscillation of the super-regenerative circuit becomes a carrier of pulsations superimposed on the high-frequency current without modifying the rate of frequency of that current.

This twenty-thousand-cycle oscillation, being imposed through the tickler coil or through an independent coil in the grid circuit, pulses along the wire to the grid and in a sense thus divides the rapid oscillations of the input current into regular groups of 20,000 to the second. Each of these groups, in the case of the 1,500,000-cycle current we are considering will be made up of seventy-five of the minor oscillations, an altogether manageable number. Even if a fifty-meter wave were in question (represent-

ing a six-million-cycle current), there would be, obviously, only 300 of the minor oscillations to each of the new groups. Should there fail to be absolute synchronism between tickler coil circuit and grid circuit as regards these exceedingly rapid oscillations, there might still be perfect synchronism as regards the 20,000-cycle groups which may now be considered as, in effect, the units of frequency of the oscillating current.

These 20,000-cycle groups, in this view, are somewhat closely comparable to the "beat" groups of the heterodyne method; but they have been imposed on the current without the conflict between nearly synchronous alternations of local and input currents that characterizes the heterodyne method. In other words, the force of the original current is unimpaired, and its phases are amplified to the full limit by the familiar regenerative principle; and the 20,000-cycle pulsation comes as a fortifying influence, permitting the retention of all the good qualities of the original current and adding to it an element susceptible of further amplification.

As was just said, Major Armstrong commends the three-tube super-regenerative circuit as giving readiest opportunity for bringing out the three functions in question. He points out, however, that different combinations in practise are peculiarly adapted to the respective needs of continuous wave radio telegraphy, interrupted continuous wave radio telegraphy, and radio telephony. In the most elaborate circuit, the first tube acts as regenerative amplifier, the second as oscillator, and the third as detector.

In another circuit, the first tube acts as amplifier and detector, and the second as oscillator. And in a third circuit, a single tube acts simultaneously as radio-frequency amplifier, oscillator, and detector.

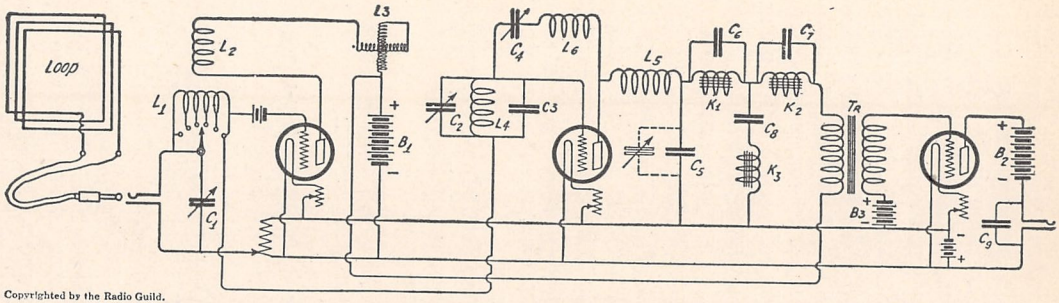
A fourth circuit may be made by adding an ordinary audio-frequency amplifying tube to the single-tube super-regenerator. And this constitutes, as already noted, an

outfit that, operating with a three-foot loop antenna (ten or twelve turns of wire in a single plane), gives a loud speaker record that, on the occasion under review, amply filled the large auditorium at Columbia University. The speech and music thus registered came from the transmitting station WJZ, at Newark, N. J., about twenty-five miles away. And the hall in which the demonstrations were made is in a building, as Major Armstrong pointed out, of steel and concrete construction, with a copper roof. Concrete walls, of course, offer no appreciable obstruction to the radio waves; but metal structures exert a deflecting influence, as various experiments have demonstrated. The directional flight of radio waves may be modified as they pass near such structures; but it does not appear that the waves themselves are otherwise interfered with. At all events, those that find their way to the loop antenna thus installed within the steel structure performed their usual radio function when intercepted by a loop antenna, as we have seen.

With this aspect of the subject, however, we are already familiar through our studies of the radio-frequency amplifier of non-regenerative type.

### ROLLS-ROYCE VERSUS FLIVVER

It must not be supposed that the super-regenerative receiver is likely to supplant all other types of radio-frequency amplifiers. Such an expectation would be lacking in plausibility. We have seen that a radio-receiving apparatus utilizing two or three stages of radio-frequency amplification, a detector, and two or three stages of audio-frequency amplification constitutes an outfit that operates with a small loop antenna in a steel building or elsewhere and trumpets the message from a loud speaker quite after the manner of the super-regenerative apparatus. It will be recalled that Major Armstrong did not use such an apparatus as this for compari-

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HOOK-UP OF ONE OF THE ARMSTRONG SUPER-REGENERATIVE CIRCUITS USED BY MR. KENNETH HARKNESS, OF THE RADIO GUILD, IN BUILDING A VERY SUCCESSFUL RECEIVER

Specifications: $L_1$, $L_2$. Vario-coupler. Variable condenser $C_2$, 001 microfarad, shunted by fixt condenser $C_3$, 001 microfarad. Coil $L_4$, duolateral, 1,250 ohms resistance; $L_5$, duolateral, 1,500 ohms resistance; the two not inductively coupled. Condenser $C_4$, 001 microfarad, and radio-frequency choke $L_6$, 5 millehenries, couple plate and grid of second tube. A filter ($K_1$, $K_2$, $K_3$, $C_5$, $C_6$, $C_7$, $C_8$) protects the third (audio-frequency) tube. The chokes, about 0.1 henry. Condensers: $C_6$ and $C_7$, .002 mf.; $C_5$ and $C_8$, .005 mf., or .004 shunted by variable condenser (dotted line), .001 mf. The variometer is inserted as a substitute for additional windings on the rotor of the vario-coupler ($L_2$) which serves as tickler coil. "B" batteries, 100 to 120 volts.

son, but only a three-tube outfit, with detector and two stages of audio-frequency amplification. This was an eminently fair presentation; inasmuch as the chief point to be brought out by exhibition of the super-regenerator was the possibility of getting remarkable work out of a small number of tubes.

The inventor himself, in the course of the address before the Radio Club, declared emphatically that the super-heterodyne receiver, of his earlier construction, is still the de luxe apparatus,—the Rolls-Royce of the radio world. He humorously completed the comparison by pointing to the single-tube super-regenerative receiver, as depicted on the steriopticon screen, with the comment: "But some of us, of course, must use Fords, however much we would appreciate a Rolls-Royce."

The implication of that pleasantry, obviously, is that the super-regenerative circuit is chiefly to be credited with economy of materials and simplicity of action, rather than with unprecedented aggregate efficiency. It is a case of making three tubes at most do the work of nine,—a matter of no small significance, considering the cost of the tubes themselves and of the auxiliary apparatus, including transformers, associated with them. Very few amateurs can hope ever to become possessors of a nine-tube super-heterodyne equipment; but very many amateurs might construct for themselves, and doubtless were already constructing for themselves on the day following Major Armstrong's address, super-regenerative receivers using one tube for radio-frequency amplifier, oscillator, and detector, and a second tube for audio-frequency amplifier.

In proportion as they work successfully in following Major Armstrong's present achievements, such experimenters find themselves equipped with a two-tube radio receiving apparatus that enables them to do away with outside aerial and yet, with the aid of a loud speaker, to

fill the house with words or music from the broadcasting station forty or fifty miles away.

And that is an accomplishment which is remarkable from any viewpoint, and which will seem all but incredible to experienced amateurs who know the limitations of the two-tube or three-tube radio-receiving outfits hitherto available.

### HIGH-FREQUENCY COMPLICATIONS

It seems a reasonable presumption, however, that the super-regenerative principle has possibilities of applications that give it far greater importance than those implied in what has just been said. In this view, the super-regenerative receiver is not to be regarded as a mere cheaper substitute for more elaborate receivers. Just as the heterodyne principle (originally suggested by Professor Fessenden, but made possible of application through Major Armstrong's original discovery) opened up new aspects of radio art; so, we may believe, will the principle of feeding-back a slightly super-audible carrier oscillation open up yet other fields.

The particular field into which the super-regenerative principle seems most directly to lead is that of short-wave radio transmission and reception. Short waves, as we know, are the coadjutors of very high-frequency carrier current; and it is such currents that have proved particularly difficult to handle when radio-frequency amplification is in question; and particularly when such amplification is associated with use of a regenerative circuit.

However the engineer may explain it, the layman does not find it strange that practical difficulties are encountered when one tries to blend (through inductive transfer between tickler and secondary) two currents each supposedly oscillating at the rate of 1,500,000 cycles per second. Two separate circuits are involved, as we know;

and the slightest variation in the product of inductance and capacitance in the two circuits must result in a greater or less departure from the exact frequency; and this obviously implies that there ceases to be exact coincidence between the two sets of vibrations if, indeed, such coincidence was ever attained.

But it is obvious that any departure from exact coincidence of oscillation must result in a corresponding measure of distortion. It is very easy indeed to maladjust one circuit or another in such wise that the two currents differ by 1,000 to 10,000 oscillations per second (the difference between 1,500,000 and 1,499,000 is relatively infinitesimal); that is why it is so easy to get unwelcome screeches and squawks and whistles from the receiver,—unintended and highly undesirable heterodyne effects.

With the super-regenerative circuit, Major Armstrong tells us, new series of undesired sounds are elicited through maladjustment, the significance of each to be recognized only by the experienced ear; but it has already been explained that the new 20,000-cycle grouping makes it possible to ignore, more or less, minor discrepancies among the small oscillations. The 20,000-cycle groupings are imposed by a "B" battery of perhaps 200-volts and, entering into the scheme of regeneration, they impose themselves on the input circuit as a dominating influence.

Of course the original modulations of the input current are retained, proportionately amplified, in the modulations of the 20,000-cycle current. Considered as groups (and only thus can they ultimately affect the telephone) they are of course even larger pulsations, inasmuch as they are of audio-frequency. Moulded by them, the 20,000 cycle current thus represents the pulsations of the transmitting microphone; and it is this dominating current, going through the tickler coil and thus further regenerating the input current in turn, that is susceptible of almost indefinite amplification, undisturbed by any

jangling that may occur among the high-frequency component oscillations.

The modulated 20,000-cycle current becomes in effect the major swell of an ocean surface, in viewing which we disregard the minor ripples that dimple the surface.

### THEORETICAL CONSIDERATIONS

Most of this would be unintelligible had we not learned, through earlier study of the radio current, to think in terms of high frequencies and to visualize, more or less, conditions obtaining in radio circuits.

Attempting such visualization now, we are able at least in a measure to understand why the super-regenerative circuit permits the handling of currents of very high frequency (representing correspondingly short waves), and even why it is that the degree of amplification possible is increasingly greater as higher and higher frequencies are attained.

It is obvious that amplification must tend to separate the minor wavelets and thus to give them greater relative individual significance. We saw that there are seventy-five such wavelets in the case of the 1,500,000-cycle current for each major wave of the 20,000-cycle current. Individual discordances here would be more significant, obviously, than in the case of the 6,000,000-cycle current, where there are 300 minor wavelets to each of the larger billows. Each individual wave of the 300 is relatively much less significant.

And if we were to deal with radio waves of ten-meter length, as is suggested, the corresponding high-frequency current has 30,000,000 oscillations per second, or 15,000 to each wave of the super-regenerative current. The energy represented by each individual vibration of the 1,500 must be insignificant indeed; and discordances between two groups of such minute waves must be enormously magnified before they would appreciably distort the sur-

face of the amplified 20,000-cycle carrier current.

It is such considerations that justify the hope that the super-regenerative circuit will enable the radio operator to deal with waves of the series below 150-meters, which have hitherto been for the most part beyond the range of successful utilization.

### REFLECTING AND DIRECTING RADIO WAVES

The possibilities of increased selectivity implied in the use of short waves has been referred to. Another possibility, of tremendous significance, is revealed in the fact that experiments have shown that short radio waves can be reflected, with a specially devised electrical apparatus, and directed toward a determinate point, just as a beam of light is directed. Experimental demonstration of this fact has been made by no less distinguished an experimenter than Senator Marconi himself. The famous pioneer of radio, in his address before the Institute of Radio Engineers in New York, June 21, 1922, told of experiments, conducted at first in Italy, and subsequently extended by his associate, Mr. C. S. Franklin, in which short radio waves were directed

SENATOR GUGLIELMO MARCONI

This shows the "Father of Radio" as he is to-day, still a young man, and in the forefront of radio activities.

in such wise that messages were transmitted directly to a determinate goal with a distance of one hundred miles between transmitting and receiving stations. It was declared that, whereas any one with a radio-receiving apparatus in the direct line between the two stations could have interpreted the message, the radio waves that carried it would nowhere else have been appreciable.

The possibilities of secret radio transmission thus opened up have obvious significance. There is tremendous value also, so Marconi believes, in the possibility of directional communication between ship and ship or between ship and shore, to the end that collisions and drowning accidents may be averted in time of fog.

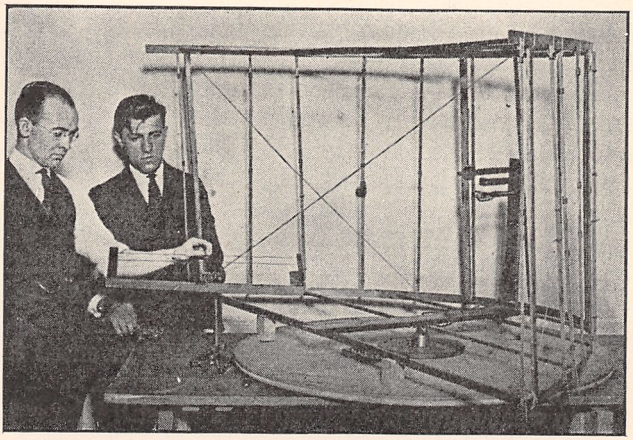
On the occasion of his appearance before the Radio Engineers, Senator Marconi exhibited a reflecting apparatus, operating across the lecture platform, which was said to handle waves only one meter in length,—representing, therefore, a generating current of 300,000,000 oscillations per second. It was already accepted by experimenters that the triode is capable of generating oscillations of such unimaginable frequency, and maintaining them, under uniform condition of the constants of inductance and capacity, indefinitely.

If with the aid of the new super-regenerative Armstrong circuits, or similar expedients, it becomes possible to handle such currents effectively at the receiving station, even without thought of directional transmission, a new era in the history of radio is opened up.

Theoretically at any rate, it should be possible, when such frequencies are in question, to tune an apparatus to select between waves differing in length not by meters but by centimeters or even by millimeters. At all events, the number of wave lengths available would be multiplied almost indefinitely, eliminating interference to an extent hitherto undreamed of. With waves of the order of one meter in length, the change of a *millimeter* is equivalent as regards frequency of generating current to a change of

300 meters, with waves of the order of those used in present broadcasting stations.

But when in addition we consider the possibility of directional sending, it is obvious that there would be still



AN APPARATUS FOR REFLECTING RADIO WAVES

This is the apparatus shown by Senator Marconi and used to demonstrate the reflection of exceedingly short radio waves before the Institute of Radio Engineers in New York, June, 1922. When asked whether a similar apparatus could be made to reflect the long waves used by the commercial station at Radio Central, Long Island, Marconi is said to have replied that this would be theoretically possible, but that the reflecting apparatus would need to be nine miles in length—that is to say, the length of the radio waves used at that station. Such a condition is not necessarily prohibitive, inasmuch as wave-length antennæ are used at the station.

greater range of selectivity attained. A measure of secrecy in radio communication actually greater than that at first attained in ordinary telephone communication seems within the possibilities of the near future.

Such are some of the vistas that open before the mind if we permit the imagination to range a little under stimulus of consideration of Senator Marconi's experiments

with the directional transmission of short radio waves, and Major Armstrong's demonstration of the possibility of handling such waves effectively with the super-regenerative apparatus.

With the consideration of the announcement of these pioneer workers—announcements that chance to be made almost simultaneously—we have witnessed the newest development of aspects of the radio art that are of concern to every amateur. It would be hazardous to predict as to what the morrow may bring forth; but present accomplishment surpasses anything that the most visionary dreamer would have thought possible a generation ago. No doubt Dr. De Forest was fired with enthusiasm when he made his experiments that culminated with the placing of a little grid in the vacuum tube; but his most fervid imaginings could but vaguely have adumbrated the possibilities inherent in the apparatus he had invented that within a decade or so were to become realities.

As to what unrevealed possibilities are still inherent in the magic tube, it would be futile to attempt to surmise.

## CHAPTER X

## SENDING RADIO MESSAGES

OF course the great mass of users of radio-receiving telephones will never aspire to become senders of radio messages. At least, that seems to be the present-day probability. It is possible that new methods, at present unpredictable, may presently be available that will make personal intercommunication more feasible than at present by radio. But for the moment the great function of radio is to supply multitudes of artificial ears to be reached by a few artificial voices.

We must not overlook the fact, however, that there is a vast company of amateurs—numbering perhaps 15,000—who are persistent senders of messages; and there is no reason why any ambitious novice should not presently graduate into this class. As we have followed through the development of a radio-receiving outfit, from the simplest type to a relatively complicated and highly efficient multi-stage amplifier, we are now in position to make inquiry as to the next step to be taken if we are to box the entire radio compass, so to speak.

In other words, we are to enquire how we may become transmitters of radio messages, instead of mere passive receivers.

Let it be said at once that the differences between radio sending and radio receiving are not so fundamental as might be supposed. In reality, there is no fundamental difference at all. Every receiving apparatus that uses the electron tube is potentially a sending apparatus—not

a good and efficient one, to be sure, but a potential transmitter none the less.

The point is simply that there are possibilities of the development of an oscillating current in every electron tube; and that with every outfit using the regenerative circuit, these possibilities may readily be realized. We have already learned something as to the heterodyne or "beat" method of receiving, which depends upon the principle of generating local oscillations in an electron tube, to be coordinated with the oscillations of the incoming current. We have learned, too, that on occasion the receiving tube may become a disturbing factor, through generating such oscillations, actually sending out waves that make their way to neighboring antennæ, to be registered in the ears of various radio listeners as "squeals" or "howls" of most objectionable character. I was told recently of a boy who tried to play "Home, Sweet Home" on a receiving tube and succeeded so well that he created consternation in many homes, until he was located with a direction-finder. He had been blissfully unaware that he was doing anything out of the way.

This incident in itself evidences the transmitting possibilities of the receiving radio mechanism. Such an observation prepares us to understand that the radio mechanism intended for transmitting messages shows the fundamental characteristics of the electron-tube receiving set. We have to do merely with a reversal of conditions. The receiving set gets an oscillating input current from the wire, generated there by the radio waves. The transmitting set sends an oscillating output current to the aerial, there to generate the electromagnetic waves. In each case the essential mechanism that handles the high-frequency current is the electron-tube.

It is true that there are other transmitting apparatuses. The high power commercial stations use generators that are similar to the dynamos of the power houses. But they deal with telegraph messages, and are not concerned

with the modulated currents required in radio telephony. The broadcasting stations, on the other hand, use triodes for transmitters; and of course the amateur is concerned with nothing else if he is to send radiophone messages; and, for that matter, will not think nowadays of installing any other type of transmitter than the electron-tube outfit, even if he is especially interested in radio telegraphy rather than in radio telephony.

### SOME GENERAL PRINCIPLES

This being understood, it is obvious that what we have learned about radio-receiving outfits will stand us in good stead now that we are to consider the installation of a transmitting outfit. We have by no means to begin our studies all over again. The apparatus with which we will deal is a familiar apparatus. We are prepared to install a transmitting set so soon as we can learn the telegraphic code, enabling us to pass the requisite examination. But it must not be overlooked that we cannot begin sending, even with the simplest buzzer set, until we have secured authorization to do so. And that can be gained only by learning the telegraphic code (International Morse), and becoming sufficiently proficient so that we can receive and properly interpret at least ten words per minute. Three or four months' practise and study will be required before we can meet this condition. For purposes of the present chapter, however, we shall assume that the condition has been met, and we shall make specific inquiry as to just how to install a transmitting radio set.

As preliminary to detailed examination of this question, however, it may be well, partly by way of recapitulation, to consider the general principles involved, viewing the subject of oscillating currents and radio waves from the standpoint of the generating station rather than from that of the receiving outfit. The difference is not funda-

mental; but it involves some modification of points of view and will give opportunity for the presentation of some details that have not hitherto claimed our attention.

We have seen that modern science interprets all electrical phenomena in terms of electrons. It appears that what we call an electric current merely evidences the rush of hordes of electrons along a conducting medium, usually a wire. It appears, further, that each electron has about it a magnetic field; and that the lines of magnetic forces, dragging through the ether, set up waves, like the wash of a boat, that go rippling off in every direction. Many familiar types of electric light currents, including generators in power houses, and such minor instruments as the X-ray and high-frequency apparatus of the physician, produce oscillating currents in which there is always the association of inductance and capacity that results in the development of electromagnetic waves that go rushing off in every direction through the ether at the rate of 186,000 miles, or 300,000,000 meters per second.

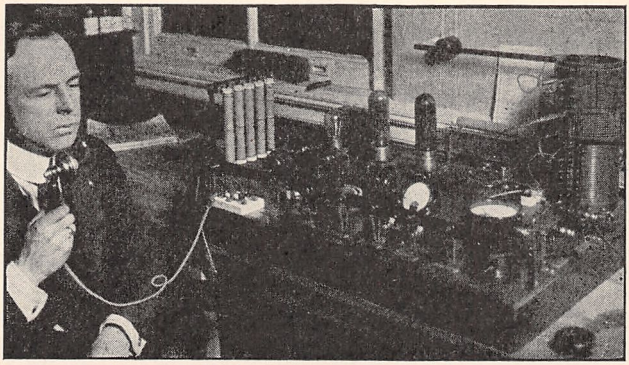
Such waves are apparently developed, whether or no, whenever an electric current of this character passes along a wire. Whoever generates such an electric current, by what method soever, is thus signaling off into space, making ripples in the ether that imagination likes to conceive as passing on and on forever through space, into starland and through starland to the confines of the universe.

But the ordinary worker with electricity gives no thought to these stray waifs of his accidental begetting; perhaps he is unconscious of their existence. They mean nothing to him, and they convey no intelligible message to any one. It is only when conscious effort is made to control the development of the electromagnetic waves that these offsprings of the electric current come to have significance in human affairs. The nature of the controlled electromagnetic waves is in nowise different from that of the stray waifs; but because they are controlled

and utilized as the medium of intelligent communication, they assume an utterly new significance. We may conveniently refer to them, as we have done hitherto, as radio waves. The mechanism that generates them is a radio transmitting apparatus.

We have now to consider what are the essential characteristics of such an apparatus.

The essentials of such a system are: (1) a generator



Courtesy "Radio News," N. Y.

AN AMATEUR TRANSMITTING OUTFIT

Mr. Thomas J. Williams, of Washington, D. C., who broadcasts entertainments for the local amateurs. (Courtesy of *Radio News.*)

for the production of an alternating current of electricity at high tension; (2) an insulated conducting (wire) circuit about which the electric current can oscillate, with its magnetic field in frictional contact with the ether; and (3) some device for interrupting or modulating the flow of the current periodically, so that the electromagnetic waves generated in the ether shall flow out as an interrupted or a fluctuating current.

Let us see how these general conditions are met in practise. In other words, let us see how we are to go about

the building of a simple type of transmitting radio station.

### THE TRANSMITTING ANTENNA

It is obvious at once that our initial problem has to do with electric currents. Our ultimate object is to generate electromagnetic waves in the ether; but we have already become aware that the only way to do this is by marshaling the electrons into proper cohorts and causing them to move about in a conducting system. The conducting system that has been devised to meet this end is called an antenna. The name is not very appropriate, for the word "antenna," in its original usage, implies a "feeler" for the reception of impulses. The transmitting radio wire does not feel for anything, nor receive anything; its function, as we know, is to send out impulses.

But distinctions like this never stand in the way of acceptance of convenient words; and the name antenna is securely fixed in radio parlance, and altogether familiar to technician and layman alike.

The novice may not understand, however, that the word, when used in a comprehensive sense, applies not merely to the familiar set of wires called the aerial, but to the lead-in wires that connect this with the compact portion of the mechanism that is usually indoors; to certain portions of this mechanism itself; and to the grounding wire to its utmost terminus in moist soil or water. Yet such is the fact.

An aerial by itself, however well connected with battery and other localized parts of the sending mechanism, would not function if disconnected from the earth, unless a substitute "counterpoise" has been provided. Such a counterpoise may consist of a wire or set of wires more or less duplicating the aerial, usually stretched directly beneath it, much nearer the earth's surface, connected with what would ordinarily be the "ground" wire of the radic mechanism.

Such a counterpoise may serve effectively as a substitute for a moist ground connection, permitting the electrons that make up the current to surge back and forth through the sending mechanism, as is essential to the development and control of the electromagnetic waves.

In all these regards, as in its detailed construction, the sending antenna does not differ essentially from the receiving antenna with which we are already familiar. About the only practical difference is that experience has shown the desirability of installing the transmitting aerial at a considerable elevation. There are advantages, also, in a several-wire type of aerial for the transmitter, whereas a single relatively long wire serves better for the receiving aerial than several shorter strands aggregating the same length.

The simple flat-topped "T" aerial, of about four strands, separated by three or four feet, is most generally employed. The inverted "L" type, however, has certain advantages if directional sending is desirable (as in transmitting across the Atlantic), inasmuch as the electromagnetic waves that radiate from it tend to be concentrated somewhat, or to have greater power, in the direction in which the "knee" of the aerial points.

Other types are the "cage" aerial, not much used except in military service, but gaining in popularity; and the umbrella aerial, the name of which fairly indicates its shape. The umbrella type is a poor transmitter, although it may be a fairly good receiver.

Further details of construction of antennæ need not detain us here, as we are concerned at the moment with the simplest type of transmitting mechanism, and in particular with the principles of its operations, which are the same for all.

### WIRE-LENGTH AND WAVE-LENGTH

The point to be emphasized at the moment is that the aerial is only one of the balancing parts of the antenna,—

an important part, of course, yet no more important than several other portions of the transmitting mechanism, inasmuch as all are essential.

There is considerable probability, it may be added, that cumbersome aerials of the present familiar type will play a much less significant part in the radio of the not distant future. Up to the present, however, it has not been found possible to accomplish long-distant transmission effectively without the aid of the long stretches of wire which the aerial and associated ground wire furnish. This familiar fact is far better established than a theory in explication of it.

Technical theories aside, however, it does not seem strange to the layman that there should be at least a general relation between the length of the antenna system and the length of the electromagnetic waves that it generates. That the oscillation of a current to and from a long aerial should tend to be relatively slow, is rather to be expected.

The analogy of the slow physical vibration of a long piano cord or a violin string suggests itself. And of course slow oscillation means a longer period between the generation of successive electromagnetic waves; and that in turn implies longer waves, since waves of radio move at uniform speed through the ether.

It must be recalled, we may note emphatically, that "slow" oscillation in the present sense does not imply slowness in the ordinary acceptance of the word. Oscillations at the rate of thirty thousand or fifty thousand per second are to be rated as slow in the radio sense. Rapid oscillations are those that take place at the rate of a million or more per second.

The experimental technician even tells of having attained a one-hundred-million-per-second rate of oscillation.

Such figures, of course, convey no definite meaning to our minds. Our sensibilities are too blunt to enable us

to visualize such activities except in a vague and general way. We can only marvel at the inventive genius of the minds that have devised methods to put the electron through such paces at will, predetermining their inconceivably rapid journeyings. We have now to enquire just how this is practically accomplished.

If you listen to a technical account of the matter, you will hear that the aerial above the ground wire and moist earth which is connected below are in effect plates of a gigantic condenser with the air between acting as dielectric; and that the entire antenna system is an electric system having resistance, inductance, and capacity. But unless you have some antecedent knowledge of electricity, these words will convey a very vague impression to your mind.

Doubtless there are many practical users of radio to whom the words have no very definite implication. Certainly there are thousands of users of receiving radio telephones to whom the words resistance, inductance, and capacity, in their technical usage, have no clear meaning.

But most people like to understand the tools they are using, and it may fairly be said that unless we have a somewhat definite idea of the meaning of the words just cited, in their application to electrical phenomena, we cannot have the clear conception that every user of radio should have of the fundamentals of the subject.

On the other hand, when we have gained a definite idea, in particular of the meaning of "inductance" and "capacity," and have seen how "inductances" and "capacities" are used in the radio mechanism, we shall at least be in the position of the enquiring child who has seen the wheels of the watch go round, even if he does not fully understand the action of the mechanism.

### THE ELECTRICAL CURRENT AND RADIO RESISTANCE

We have to do, it will be recalled, with an alternating current of electricity; which implies, in terms of modern

theory, a horde of electrons temporarily loosed from their atomic moorings, and surging violently backward and forward along a conducting wire.

The source of this current may be, in case of a commercial radio-transmitting station, an alternator or dynamo similar to that of an electric light plant. In a small amateur transmitting plant, electricity may be supplied by a storage battery.

Ignoring for the moment all details of generation of the alternating current, we witness the current flowing into the radio-transmitting apparatus, impelled by a so-called electromotive force (E.M.F.) which virtually pushes the electrons forward somewhat as a crowd of people in a narrow hallway might be jostled together and forced to move along by some one (a cordon of policemen, let us say) pushing those at the rear.

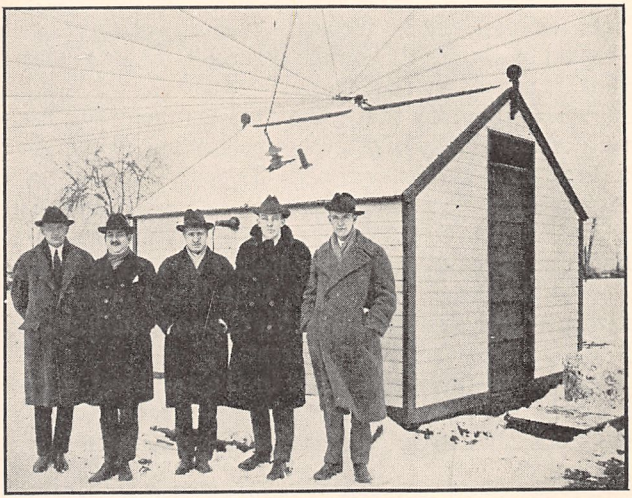
At first glance, this comparison may not seem a valid one, because there may seem to be no encompassing wall about the wire along which the electrons move; but in reality the air about the wire serves as an insulator. Meantime the atoms from which the electrons come have been made positive because of the exit of the negative electrons; and thus tend to draw the escaping fugitives back again;—the net effect being that the surging electrons constituting the alternating current are crowded close to the surface of the wire and prevented from escaping laterally as effectively as the crowd of people in the hall are held by the lateral walls.

In each case, the question is, what channel of escape is there ahead?

We need not concern ourselves further with the crowded hall, but in following our jostling crowd of electrons, we find that the avenues of escape provided them are supplied by wires leading in one direction to the aerial and in the other to the ground. As pressure from behind continues, the hordes of electrons will try first one of these channels and then the other, oscillating between them,

with inconceivable rapidity. In either direction, there are difficulties in the way of their flight; but our chief concern is with the resistance offered in the direction of the aerial.

Following the electrons in this course, it appears at



OWNERS AND OPERATORS OF THE AMATEUR STATION 1BCG

This station, owned and operated by Messrs. Amy, Grinan, Burghard, Armstrong, Cronkhite, and Inman, was the first station to send a complete message across the ocean in the celebrated test of December, 1921. The station is at Greenwich, Connecticut, and the message was received by Mr. Paul F. Godley, at Androssan, Scotland. The photograph shows, from left to right, five of the owners in the order above named, Mr. Inman not being present.

once that the number of oppositions they encounter is nothing less than disheartening. Professor J. H. Morecroft, in his notable technical book, summarizes the factors contributing to the resistance of a radio circuit in general terms as including: (1) Resistance of the conductor itself; (2) resistance of the neighboring closed

circuits and their proximity; (3) magnetic material close enough to the circuit to be magnetized by it; (4) losses in the dielectric of any condenser in the circuit; (5) corona losses from gaps in the circuit; and (6) radiation of electromagnetic energy.

All of these factors, he says, vary with the frequency of the current in the circuit, some of them with a magnetic radiation set up by the circuit and some with the electric radiation set up by the circuit.

It will be obvious that some of these factors of resistance operate chiefly within the mechanism of the radio-transmitting apparatus proper. These we shall have occasion to examine in connection with study of inductance and capacity. As to the parts of the mechanism commonly thought of as constituting the antenna we may note, again following Professor Morecroft, that losses occur in the network of wires and in the earth due to actual heat loss produced by the induction current.

Such losses imply resistance in the technical sense of the word. Further resistance is incident to the losses due to induced currents in guy wires and any other neighboring wires.

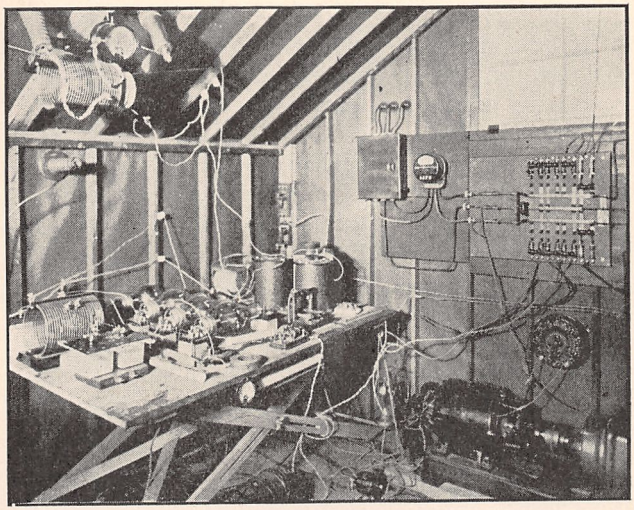
Then there is loss in the earth's surface and in any other dielectric in the field of the conductor, such as trees.

Finally there is resistance implied in the ultimate radiation of power, evdenced by the setting up of the electromagnetic waves; and this final resistance is the only useful one. All the other oppositions were stumbling blocks in the path of the electron, interfering with the performance of this final function. But all of them must be considered in calculating the efficiency of the current as an ultimate producer of electromagnetic waves.

In general terms it may be said that with very high frequency the resistance is high. A little more technically, according to Professor Morecroft's estimate, "it decreases to a minimum at a frequency about twice that of the natural oscillation of the antenna (without any added

inductance) and then rises gradually, the amount of this rise being determined principally by electric losses in objects located in the electrostatic field of the antenna."

Technicalities of measurement of the resistance of the antenna need not at the moment concern us. We may



INTERIOR VIEW OF STATION 1BCG

Details as to the equipment of this station are given in the table of successful transatlantic amateur stations shown on a later page of this chapter.

note, however, that resistance is relatively high for small antennæ such as the amateur would use under ordinary circumstances.

It seems necessary to present this summary view of the obstacles encountered by the electrons that do the bidding of the radio transmitter, in the attempt to gain a clear conception of what we are really doing when we put together a radio-transmitting apparatus.

### THE MATTER OF INDUCTANCE

Glancing back at the summary of sources of resistance to the current in the radio apparatus, as above presented, we find one of these named as: resistance of neighboring closed circuits had their proximity.

This might have been stated otherwise as resistance due to electromagnetic induction. And it may now be added that the sum of such resistances in the entire radio-transmitting mechanism constitutes the "inductance" of that mechanism.

This factor of inductance has enormous importance, because the phenomenon of electromagnetic induction to which it owes its name is one of the essential factors upon which the operation of both transmitting and receiving radio mechanisms depends. Incidentally, it is one of the most mysterious and fascinating phenomena within the entire range of human observation. Yet it is subject in a measure to human regulation. Were it not, there would be no such thing as radio transmission of intelligible messages from one human being to another.

In the radio mechanism the induction coil might be said to occupy a place of importance comparable to that of the main spring of a watch. And as the watch may have various auxiliary springs, so the radio mechanism may have, in its highly developed forms, a series of extremely important inductances.

Certain elementary facts about the operations of a simple induction coil are familiar to every one who has the slightest knowledge of electricity. It will be recalled that such an apparatus consists ordinarily of a coil of relatively large wire running the length of a cylinder, its ends connected with a battery; surrounded by and insulated from a cylinder upon which a coil or a series of coils of much smaller wire makes up a much longer and quite independent circuit.

These coils are called respectively the primary and the secondary coils.

The secondary coil has its ends connected to make a closed circuit, but is unconnected with the battery; and in this coil a current of electricity is developed by induction whenever the circuit in the primary coil is opened or closed. The current induced in the secondary coil when the primary circuit is opened flows in the opposite direction from the current in the primary coil; and the current in the secondary is reversed when the circuit is closed.

By making and breaking the current rapidly in the primary coil (as is usually done automatically by the action of a magnet), an alternating current of corresponding frequency is induced in the secondary circuit.

The extraordinary feature of the transaction is that the moving electrons constituting the current in the primary circuit have apparently stimulated to riotous action a cohort of electrons along the wire of the secondary coil, notwithstanding the fact that the two coils are separated by a medium that makes transit of the electrons themselves from one to the other impossible. How is this explained?

The answer suggests itself if we reflect that, according to an hypothesis we have already examined, each electron is in effect a miniature magnet, surrounded by a magnetic field, the limits of which are scarcely definable. And when groups of electrons are moving together, they enmesh the space adjacent to their path with lines of magnetic force that pay no heed to ordinary insulators.

These lines of magnetic force sweep across the magnetic fields of the electrons in the wires of the secondary coil and set up a commotion among them which we interpret as an induced electric current.

The explanation leaves a great deal to be desired; particularly when we reflect that we have no knowledge at all as to what may be the real nature of a line of magnetic force. Magnetism is as mysterious as gravitation.

But, like gravitation, it manifests itself in a tangible influence over material substances (of some types only—whereas gravitation has no restrictions), thus enabling us to learn a great deal about it. And from the present standpoint the important thing that we learn is that an electric current moving along the wires generates a magnetic field about it; and that this magnetic field may in turn generate an electric current in a neighboring wire-circuit.

The mutual relations between electricity and magnetism are the basis, as is well known, of the action of the dynamo which is the familiar source of power; and we now see this relation utilized in the practical equipment of the radio apparatus.

Thanks to this principle, we can transfer energy from one closed system of wires to another without actual contact; and in so doing can modify indefinitely in either direction the voltage or force (potential) of the current by modifying the size of wire and the length of wire in the various pairs of primary and secondary coils.

To bring about such changes of power of current (what the electrician calls electro-motive force) in different parts of the apparatus, is one of the functions of the "inductances" in the radio equipment.

An induction coil having a short coil for primary and a long coil for secondary increases the electro-motive force in the induced current in proportion to the difference in the length of the two coils; and is called a step-up transformer. By reversing the relative length of wiring of primary and secondary coils, we have a step-down transformer, decreasing the voltage of the current in the same proportion.

It is not merely the influence of one current-bearing wire on another that has to be considered, however, by the radio engineer. There is the important question of the energy involved in what is called self-induction; that is to say, the amount of energy stored in the magnetic field

of a circuit, when there is no other circuit near to intercept it. In the current in the aerial, for example, in a high-power radio-transmitting station, large allowance must be made for the energy in the surrounding magnetic field.

It is this energy, combined with that of the electric field, which we are about to investigate, that is transmuted into the energy of the electromagnetic waves for radio signaling.

The inductance of a radio system is, then, to be thought of in terms of the total amount of energy stored as magnetic force in the ether about all the wires of the entire radiating system. This energy is variously distributed. It is piled up, as it were, when wire is wound into a coil, presumably because the magnetic fields of the different strands of wire are superimposed.

The inductance of two strands of an aerial that are very close together is almost double that of a single strand.

The inductance of a tuning coil that we connect with the aerial is relatively great in proportion to the length of wire involved because of the massed effect of the coiled wire just referred to. As the tuning coil, thus arranged, constitutes part of the aerial system, the inductance of that system may be modified by cutting down the length of coil through short-circuiting it at one place or another. That is the object of the slide that is moved along the coil in the process of tuning;—a statement that correctly suggests a definite relation between the inductance of the aerial and the length of the electromagnetic waves—or radio waves—that will be sent out from it.

The other element in determining the length of those waves is the energy of the electric field, to the consideration of which we now turn.

### THE QUESTION OF "CAPACITY"

We have just seen that the word "inductance" as applied to radio has to do with the magnetic field that energizes the space about a wire in which electrons are moving to form an electric current.

We have now to consider another field of energy, the lines of which are interlaced with the lines of magnetic energy in the neighborhood of an electrified wire, to which the name of electric field is given. The ability of an electric system to store energy in the form of this electric field is technically designated "Capacity."

Capacity has already been characterized as one of the essential elements, along with resistance and inductance, of the radio system. We have now to make our inquiry a little more specific as to just what capacity is and how it is utilized in the radio system.

We shall prepare the way if we note that capacity has to do with a form of electricity that is called static, and that the particular apparatus that has to do with energy in this form is the condenser, which, in some of its simpler types, came to our attention when we were studying the receiving radio mechanism.

It will be recalled that a primitive condenser there described consists of a piece of tinfoil interleaved with insulated sheets of paraffin paper; and that the successive metal leaves were oppositely electrified—first positive and then negative in alternative sequence. It was noted also that the electrical energy stored in the condenser was not supposed to be chiefly in the metal leaves, but in the insulating leaves making up what is called the dielectric; and the suggestion was made that, according to theory, the stored energy could be conceived as holding the molecules of the dielectric in polarized successions, like a string of iron filings in a magnet field.

If it is further explained that the condenser holds its stored charge of electricity only until the difference of

potential between opposing charges reaches a certain stage, and then discharges it with emphasis, we shall have a fairly clear notion of the action of the condenser in storing a charge of static electricity. The condenser described is, in effect, a Leyden jar; or, stated otherwise, the familiar Leyden jar is the typical condenser of which the interleaved condenser just described is a modified imitation.

The condenser of the transmitting apparatus, with which we are concerned at the moment, differs from the previously described condenser of the receiving apparatus only in details of manufacture (to make it what is called a power condenser), not at all in principle.

The substitution of a piece of glass or of mica for a piece of paraffin paper, and the increase in size of the sheet, will increase the power of the apparatus, as one might expect. A condenser is made variable, as we are aware, by mounting the sheets so that one set can be moved away from the other laterally, wholly or in part. A convenient practical plan is to adjust one set of plates so that they will revolve.

There is no difference in principle between the action of fixed and variable condensers. There may be several examples of each, and of varying sizes, in different parts of the various circuits of an elaborate transmitting or receiving radio apparatus.

In diagrams showing the "hook-up" of a radio apparatus, the condenser, as we know, is usually represented as two parallel lines slightly separated, arranged transvertly; whereas inductances are shown as longitudinally placed coils. Variable condensers are distinguished by having an arrow drawn across the two parallel lines.

An alternative symbol, not so generally used, shows the condensers as two forked lines interlocked.

As we consider the function of the condenser in radio usage,—as, for example, in a simple type of spark gap transmitter,—we are led to feel that the word "capacity"

was rather happily chosen. The condenser is of such storage capacity that when it is discharged by the breaking down of the spark gap it transmits to the antenna just the right amount of energy. The condenser in the circuit serves, in connection with the inductance, to determine the capacity of the aerial system.

The aerial itself, as already mentioned, is in effect one plate of a condenser; the other plate being the surface of the earth (or rather the upper surface of moist earth more or less underground; and the dielectric being the intervening air.

The electric field, constituting the technical "capacity" of the aerial, extends in all directions about the aerial, but notably occupies the entire space between the wire and the earth below. This makes it clear why, when a counterpoise is used, it is usually adjusted directly beneath the aerial. The counterpoise, of course, takes the place of the moist earth as the other pole of the condenser.

Where two wires are used for the aerial, unless they are very far apart, their electric fields overlap. If the wires are very far apart, the value of their capacity is twice that of one wire; but as they approach and the fields overlap, the time comes when capacity diminishes rapidly, and if the two wires touch, their combined capacity is not much greater than that of a single wire. Capacity is influenced in any case by the presence of foreign bodies in the electrostatic field,—trees, poles, metal roofs, and the like.

### THE ELECTROMAGNETIC COMBINATION

It would appear, then, as was said at the outset, that elements of resistance and inductance and capacity upon which the radiating power of the aerial depends take into account not merely the aerial itself but all other parts of the wired system that are connected with it directly or through inductive or capacitive coupling.

Determination of the natural frequency of oscillation of the system (and therefore the length of waves that would normally be sent out by any particular aerial) must take all of these things into consideration. Such computations, however, are for the electrical engineer; and the average amateur must work rather by rule of thumb or make use of tuning devices supplied by the manufacturers, or else, after making rough computation, must be guided by practical experimentation.

We are primarily concerned, as has been said, with the newer types of transmitting methods, including the oscillating vacuum tube which seems likely to supersede all other transmitting mechanisms. But there is no departure from the general principles of transmission as originally utilized, with the spark gap to check the flow periodically and with a telegraph key to make and break the circuit.

In either case, attention focalizes on the aerial with its surrounding charge of magnetic and electrostatic energy. These manifestations of energy, both of them caused by activities of the electrons, may be thought of as strains, or, if you will, whirlpools in the ether. But whatever their exact character, they are manifestations of energy, and they transmit energy to the ether and radiate it off into space in all directions, as manifested in the electromagnetic waves.

Professor Morecroft tells us that the electric and magnetic fields of radiation always bear to each other a fixed relation—a relation based upon the fact that in order that the wave of electromagnetic disturbances may exist in space, the energy per unit volume of the medium possessed by the electric field must be equal to that possessed by the magnetic field.

According to theory, he says, the ethereal medium in which the electromagnetic waves move must be considered as a superimposed electric field of all the electric charges in the universe.

That statement is not quite easy to understand; but perhaps one may comprehend a little more clearly the statement that when the energy varies, as the electromagnetic waves move through space, any modification in either the electric or magnetic energy is at once compensated for by a change of preponderant form into minimized form (electrical energy into magnetic or the reverse as the case may demand), so that there is still equality of these two forms of energy; but that the aggregate amplitude of the electric and magnetic field intensities will not be as large as it was before.

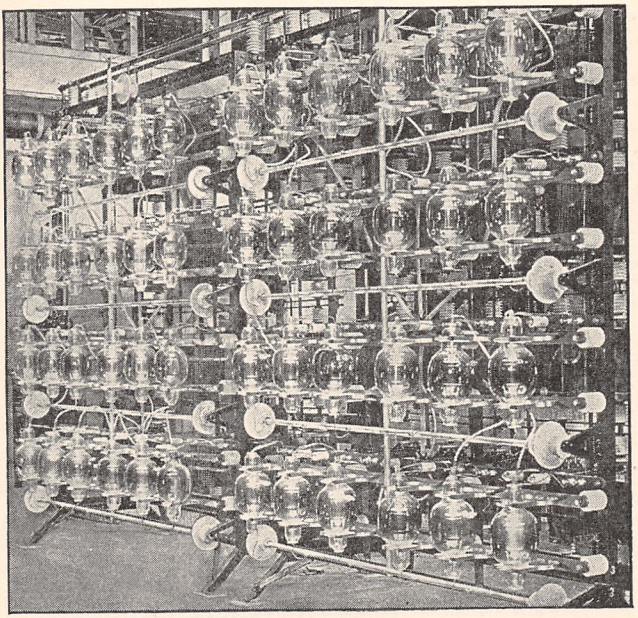
Such abstruse considerations have interest in greater or less measure for students of radio; but not the compelling interest, for the radio operator, that attaches to the observation of the practical range of the electromagnetic waves as determined by reports from more or less distant receiving stations. But even the amateur who thinks himself concerned only with practical results will scarcely question that his chance of becoming a really expert operator is largely contingent upon the acquisition of a fairly comprehensive knowledge of the theory underlying the electrical phenomena that takes place in the radio mechanism.

### THE PRACTICAL ELECTRON TUBE TRANSMITTER

Having acquired such working knowledge of the theory of oscillating currents, even if only in a superficial way, we are prepared to adjust a set of electron tubes into an electric circuit connected with an antenna system, with a microphone substituted for telephone receivers, in order that we may send out radio messages instead of merely interpreting messages that come to us, as we have done hitherto.

The triodes that are to generate the oscillations differ only in details of construction, and not in principle of action, from those with which we are already familiar.

A hook-up representing a simple transmitting mechanism, bears close resemblance to the hook-ups of radio receivers that we have all along studied. There is, however, a no-



Courtesy "Radio News."

THE MOST POWERFUL VALVE STATION

This is the station at Carnarvon, Wales, which in November and December, 1921, transmitted messages directly to Australia. The picture shows 48 transmitting valves, constituting the most powerful valve transmitter in the world. Since the photograph was taken, the number of valves has been increased to 56, each valve being about the size of a football. (Courtesy of *Radio News*.)

table departure, in that there appears, at the right of the diagram, the symbol for a transformer, of relatively gigantic proportions, connected with wires which the lettering tells us represent a 110-volt alternating current.

We may correctly infer that the wires supplying this 110-volt alternating current (usually at 60 cycles) comes from an ordinary electric light supply.

We observe that current from the secondary of the transformer goes, by way of a high frequency choke, to the plate circuit. We observe also that the filament circuits are supplied, through the medium of another transformer, with current from the same or a similar source. We note a volt meter (V.M.) in the filament circuits, and a milliammeter (M.A.) in the plate circuit. This is quite what we would expect, for of course we are aware that the regulation of the currents in plate circuit and filament circuit is indispensable. There is also an ammeter (A.M.) in the ground lead of the antenna system.

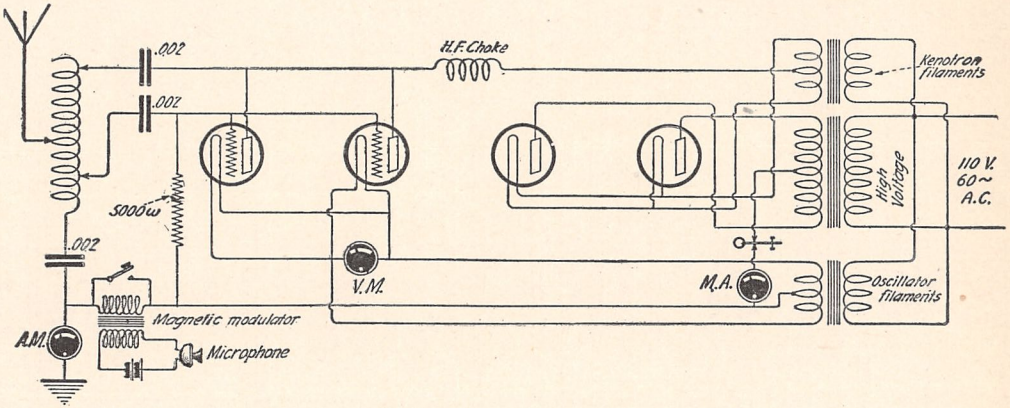
### DETAILS OF A POWERFUL AMATEUR STATION

In order to interpret these general findings in specific terms, we cannot do better, perhaps, than to cite the specifications for a relatively simple yet powerful amateur station.

As a matter of convenience, we may select the station known at 2ZL, at Valley Stream, Long Island, which was one of the successful stations in sending signals across the Atlantic to be received by Mr. Godley over there in Scotland, in December, 1921.

The hook-up shows a telegraph key instead of a microphone transmitter; for of course the tests in question were made by the sending of telegraph signals only. We are fully aware that such an equipment as this would by no means suffice to transmit the voice to such a distance. The range of the radio telegraph, power for power, is several times that of the radio telephone, as we know.

The two triodes shown in the hook-up are of the type known as 250-watt Radiotrons, UV-204; a very popular type of transmitting tube. The circuit in which they are installed is spoken of as a self-rectification circuit.




CIRCUIT DIAGRAM OR HOOK-UP OF AN AMATEUR TRANSMITTING OUTFIT

The two tubes at the right are Fleming valves, with two electrodes; the two at the left are triodes that produce the requisite oscillations. The two-electrode tubes are by no means universally employed. As a rule, triodes alone suffice. It will be seen that the original current is a 110-volt 60-cycle alternating current; and that a magnetic modulator is used in connection with the microphone transmitter.

Here is the interpretation of the hook-up, as given in the *Wireless Age* of March, 1922:

"A transformer, with a split secondary, supplies A.C. for plate potential at 2,200 volts for each tube, 4,400 over all. The filaments of the tubes are heated with A.C., by means of a transformer, also with split secondary.

"The value of the grid leak resistance used in shunt to the grid condenser is 20,000 ohms, and the capacity of the grid condenser .002. The antenna at 2ZL is an inverted L, 85 feet high at the end away from the station; and 65 feet high at the station end. The flat top is 120 feet long. The leads, four in number, are from the low end. The fundamental wave length of the antenna is 210 meters. The antenna points southwest-northeast, with the leads on the southwest end. In view of the fact that the station was heard in England and at Monterey, Calif., at practically the same time, it seems to indicate that there are no directional effects.

"A counterpoise ground system is used, consisting of 8 wires, on spreaders, directly under the antenna, and fanned out at both ends beyond the antenna. The resistance of the entire antenna and ground system is 7 ohms and the antenna current is normally 8 amperes on 325 meters, representing approximately 450 watts in the antenna."

### OTHER TRANSATLANTIC TRANSMITTING STATIONS

The reader who may recall that some of the commercial transatlantic transmitting stations register 20 or even 50 kilowatts of power may note with astonishment that the successful transatlantic amateur station just described used less than half a kilowatt. Recalling also that the federal law restricts the amateur to one kilowatt as a maximum, it may seem altogether extraordinary that not far from three dozen American amateurs were able to make their signals heard across the Atlantic at Mr. Godley's receiving station.

It must be understood, however, that the transatlantic amateur tests in question were made under very favorable conditions: at the time of year when the atmospheric disturbances of "static" are least in evidence; and only at night. It must be recalled also that, even under these conditions, signals were heard on only a few nights; and that for several succeeding nights Mr. Godley listened in vain. A commercial transatlantic station must plan to operate not merely under favorable conditions, but under the most adverse. It must be workable in summer no less than in winter, and by day as well as by night. It would obviously be unfair to attempt comparison between stations having such diverse needs; but it is not too much to say that many experts were astonished at the success of the amateur experiments in long-distance transmission with low-power apparatus.

It will be of interest here to introduce a table giving details as to antenna systems and power used by a group of the successful amateur transatlantic stations. The table is transcribed from *Q S T*, the official organ of the American Radio Relay League, under auspices of which the transatlantic tests were made.

This table will repay careful examination on the part of the amateur who wishes to become an expert transmitter. It reveals great diversity of details; yet essential conformity to the principles of radio transmission with relatively low power and use of triodes for generators of the high-frequency or oscillating current.

It must not be overlooked that there were other successful stations that used the spark system of transmission; but the opinion of Mr. Godley himself may be cited, to the effect that this method of transmission is obsolescent. It is hardly to be expected that an amateur who is about to install a transmitting system will be interested in a method that represents a past epoch, and which will probably be given up altogether in the near future, so far as amateur practise is concerned.

## OUTLINED DESCRIPTION OF THE SUCCESSFUL TRANSATLANTIC STATIONS

| STATION | ANTENNA | ANTENNA HEIGHT | TOTAL LENGTH | GROUND COUNTERPOISE | INPUT WATTS | TYPE AND NO. OF TUBES | PLATE VOLTAGE | ANTENNA CURRENT | ANTENNA RESISTANCE | PERCENT EFFICIENCY | WATTS OUTPUT | WAVE LENGTH | CIRCUIT USED | OWNER AND STATION LOCATION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1AFV | VERTICAL CAGE 12-WIRES | 70 | — | COUNTERPOISE | — | 4-UV203 | 1000 C R | 12 TC | —— | —— | —— | 200 | REVERSED FEEDBACK | F. C. ESTEY SALEM, MASS. |
| 1ARY | T 4-WIRES | 60-50 | 110 | COUNTERPOISE | 300 | 1-UV203 | 1400 C R | 4.6 HW | 8 | 56.4 | 169.5 | 225 | HARTLEY | UNIVERSITY OF VERMONT BURLINGTON, VT. |
| 1BCG | T-CAGE 8-WIRES | 108-75 | 170 | COUNTERPOISE 15-WIRES | 990 | 4-UV204 | 2200 M G | 6.0 TC | 15.5 | 56.4 | 558 | 230 | MASTER OSC. | *SEE FOOTNOTE GREENWICH, CONN. |
| 1BDT | T-WIRES | 90-50 | 115 | COUNTERPOISE 18-WIRES | — | 1-UV202 | 400 C R | .8 HW | —— | —— | —— | 200 | HARTLEY | S. S. HEAP ATLANTIC, MASS. |
| 1BGF | 4-WIRES | 40-40 | 100 | COUNTERPOISE 6-WIRES | 150 | 1-UV203 | 1500 A C | 2.7 HW | —— | —— | —— | 210 | REVERSED FEEDBACK | P. F. BRIGGS HARTFORD, CONN. |
| 1BKA | FAN 15-WIRES | 50-30 | 85 | —— | 450 | ½ KW DEFOREST | 1500 M G | 5.2 HW | 12. | 73.7 | 332 | 225 | COLPITTS | J. E. BROWN GLENBROOK, CONN. |
| 1XM | 4-WIRES | 100-30 | 100 | COUNTERPOISE | 1000 | G E 2-VT-10 | 5000 AC500 ~ | 8.5 TC | 10.5 | 75.8 | 758 | 210 | HARTLEY | M. I. T. SOCIETY CAMBRIDGE, MASS. |
| 1YK | CAGE 4-WIRES | 27 | 155 | COUNTERPOISE | 72 | 1-UV203 | 1000 M G | 2.5HW | —— | —— | —— | 235 | HARTLEY | WORCESTER POL. INST. WORCESTER, MASS. |
| 1ZE | FAN 22-WIRES | 100-60 | 122 | COUNTERPOISE | 450 | 2-UV203 | 1500 T R | 7.0 HW | 4 | 43.5 | 196 | 375 | COLPITTS | I. VERMILYA MARION, MASS. |
| 1RU | T-CAGE 6-WIRES | 54-54 | 120 | COUNTERPOISE 6-WIRES | 297 | 1-UV203 | 1350 M G | 4.0 HW | —— | —— | —— | 204 | REVERSED FEEDBACK | R. S. MINER HARTFORD, CONN. |
| 1RZ | 4-WIRES | 43-23 | 80 | COUNTERPOISE | 150 | 1-UV203 | 1000 M G | 3.5 TC | 5. | 40.8 | 61 25 | 220 | —— | J. W. HUBBARD RIDGEFIELD, CONN. |
| 2AJW | CAGE 6-WIRES | 73-53 | 84 | COUNTERPOISE | 105 | 3-UV202 2-VT2 | 525 M G | 2.0 HW | —— | —— | —— | 200 | COLPITTS | H. S. COLLINS BABYLON, N. Y. |
| 2BML 2EH | T-CAGE 6-WIRES | 60-55 | 95 | GROUND COUNTERPOISE | 690 | 2-UV204 | 5000 T R | 7. TO 9. TC | 7 | 64.8 | 442 | 200 | REVERSED FEEDBACK | RADIO ENGINEERS CLUB RIVERHEAD, N. Y. |
| 2FD | T-CAGE 6-WIRES | 80-50 | 140 | COUNTERPOISE 10-WIRES | 500 | 1-UV204 | 3000 A C | 7.3 TC | 6 | 64.2 | 324 | 200 | HARTLEY | JOHN D. BLASI FLUSHING, N. Y. |
| 2FP | 7-WIRES | 70-70 | 100 | GROUND | 500 | 1-UV204 | 6000 AC500 | 5.0 TC | —— | —— | —— | 200 | HARTLEY | H. G. BARBER BROOKLYN, N. Y. |
| 2ZL | 4-WIRES | 85-65 | 120 | COUNTERPOISE | 968 | 2-UV204 | 2200 A C | 8.0 TC | 7 | 46.2 | 448 | 325 | —— | J. O. SMITH VALLEY STREAM, L. I. |
| 3DH | CONICAL CAGE 6-WIRES | 110-90 | 160 | COUNTERPOISE | 700 | G E 250 W | 3000 M G | 5.0 TC | 12 | 42.8 | 300 | 225 | HARTLEY | D. W. RICHARDSON PRINCETON, N. J. |
| 8ACF | V 7-WIRES | 70-30 | 100 | GROUND | — | 2-C302 | 550 C R | 1.7 | 10.5 | —— | 32 | 225 | HARTLEY | McNARY & HALL WASHINGTON, PA. |
| 8BU | —— | 30-28 | 80 | COUNTERPOISE AND GROUND | 150 | 1-UV203 | 1000 C R | 4.6 TC | —— | —— | —— | 200 | HARTLEY | J. L. RUSSELL CLEVELAND, OHIO |
| 8XV | LOOP AND CONDENSER | 65 | — | COUNTERPOISE | 980 | 2-500 W | 3750 T R | 15.2 TC | 3.5 | 82.5 | 808.5 | 200 | —— | F. S. McCULLOUGH EDGEWOOD, PA. |

*1BCG WAS OWNED AND OPERATED BY MESSRS. AMY, ARMSTRONG, GRINAN, CRONKHITE, INMAN AND BURGHARD. THE ABOVE DOES NOT CONSTITUTE A COMPLETE LIST OF THE SUCCESSFUL CW STATIONS, UV 202 NORMAL OUTPUT 5 WATTS, UV 203- 50 WATTS; UV 204- 250 WATTS C.R.-CHEMICAL RECTIFIER, T.R-TUBE RECTIFIER

### TRANSMISSION WITH TRIODE AND FLEMING VALVE

It should be added, however, that a good many transmitting stations use outfits in which the oscillating triode is fed with a current that has first been rectified by being passed through a two-electrode tube of the type already familiar to us as the Fleming valve.

A particular tube most generally used for this purpose is known under the trade name of Kenotron. The amateur outfit is likely to include two of these valves, which receive the alternating current from the high voltage transformer (as the hook-up herewith presented will show) and pass it on, after rectification to the oscillating triodes.

In the *Wireless Age* for March, 1922, there is an account of three well-known amateur stations, all of which use the same transmitting outfit, with two Fleming valves and two De Forest oscillators.

The amateurs in question are Mr. Irving Vermilya, of Marion, Massachusetts, 1ZE; Mr. A. J. Manning, Salem, Ohio, 8ZG; and Mr. A. C. Mertz, of Mount Carroll, Illinois, 9AKR. The following account is given of their transmitting equipments and of some of their individual achievements:

"The transmitting sets used at these three stations are identical. A 750-watt transformer, with 110-volt, 60-cycle primary, has three windings, one providing high voltage, approximately 1,200 volts for the plates of the Kenotron tubes, another supplies 10 volts for heating the filaments of the Kenatrons and the third provides 10 volts for the filaments of the oscillator tubes. All windings have central taps. Two Kenotrons, UV-217 and two oscillators, UV-203, are used in each of the sets. The constant frequency system is used in all three stations.

" 'Speedo,' as Mr. Vermilya is popularly known, has moved the receiving set into his house and the station is operated by remote control. The antenna of the station is of vertical fan type, of 20 wires, suspended from two

poles approximately 90 feet high. A counterpoise ground, also of 20 wires suspended under the antenna, is used.

"The C.W. signals of 1ZE station have been reported from Cristobal, Canal Zone, on the Pacific side of the Isthmus, and this station was one of those heard, and the code letters verified, by amateur stations in England, during the recent trans-Atlantic amateur tests.

"In addition to these extreme and exceptional night distances, the station has carried on regular communication with the Eighth and Ninth districts. The daylight range of the station, with straight C.W., is approximately 150 miles. A magnetic modulator is used for voice communication and distances up to 75 miles are regularly covered during daylight by voice. A separate receiving antenna, consisting of a long insulated wire laid on the ground, enables duplex operation with other stations. The normal antenna current of the station is 5.2 amperes on 375 meters.

"The station of A. J. Manning, Salem, Ohio, 7ZG, has made many exceptional transmitting records during the winter months. The set was installed on October 19 and on the same night signals from 8ZG were heard in the First, Second, and Ninth districts, and a complete message which was transmitted from 8ZG to 2EL, Freeport, L. I., was copied at Havana, Cuba.

"On the night of November 12, 8ZG and 2ZA, at Roswell, New Mexico, were in communication for an hour, exchanging traffic, an overland distance of 1,400 miles. On January 6 the signals of 8ZG were reported as of good audibility by 6ALP, at Long Beach, Calif., an approximate distance of 2,100 miles.

"A magnetic modulator is used at 8ZG and a daylight range of 100 miles is regularly covered by voice. The dependable daylight range of the set for telegraphing, using straight C.W., is 200 miles, and the regular night range, 400 miles. The antenna current of the station is normally 4.5 amperes, on 375 meters.

"The third station of the group, that of A. C. Mertz, Mount Carroll, Ill., 9AKR, in the northwestern corner of the State, has been heard several times on both coasts. As in the case of 8ZG, this station was reported from

exceptional distances the first night it was operated, and communication was established with 8AWP, Syracuse, N. Y.; 5ZA, Roswell, New Mexico, and 9AMB, Denver, Colorado, through considerable static. During January the signals of 9AKR were reported from several points on the Pacific Coast and also by stations in Massachusetts and Rhode Island. The dependable daylight range of 9AKR is 200 miles, using C.W. For telegraph communication, and voice communication, using a magnetic modulator, is regularly carried on over 100 miles. The normal antenna current of the station is 4.2 amperes, on 375 meters."

### FROM NOVICE TO AMATEUR

We shall scarcely expect to attain such results as these at the outset of our transmitting experiences. But it is stimulative to know that such results may be obtained by the accomplished amateur. They represent a mark to aim at.

After we have installed a simple transmitting outfit, made up of two triodes, with a magnetic modulator and the recording micraphone, constituting the outfit a radiophone as well as a radiotelegraph transmitter, we shall presently coordinate our receiving and transmitting apparatus either with the use of separate sets of antennæ or by using a double-switch that can throw first one and then the other in circuit, so that we can carry on actual conversations by radio just as we do now by line telephone.

It is quite feasible to do this, as any one is aware who has listened in on amateur wave lengths, and overheard the animated dialogues that vibrate through the ether. But it is obvious that there must be restriction upon the number of such conversations that can go on at once; and that accurate tuning of both transmitting and receiving instruments is absolutely essential, if the jamming of the air with unintelligible messages is to be avoided.

But we are already aware that accurate tuning is a desideratum in radio practise. Our new experience with the transmitting apparatus will at best only emphasize, in this regard, a lesson already made very patent by our use of the radio-receiving mechanism.

## CHAPTER XI

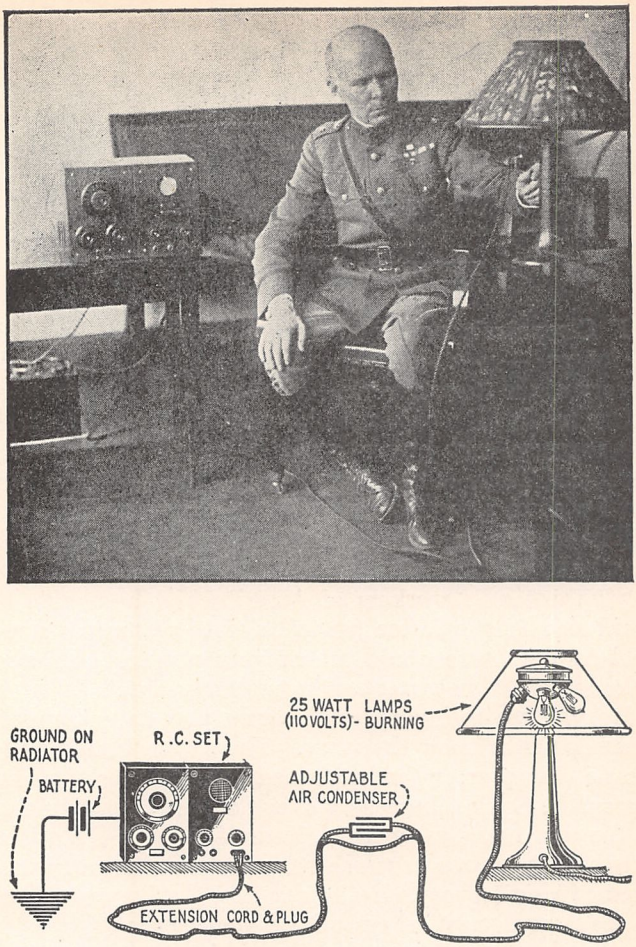
## "WIRED WIRELESS"

IF Cleopatra's nose had been a quarter of an inch longer,"—so a classical quip assures us,—"the entire history of the Roman world might have been different."

One might fill a page with historical "ifs" of greater or less cogency, each presenting an amusing or astounding paradox. There is neither time nor space for that here, but I wish to present one very modern instance which, as will be seen, is strictly pertinent to our present theme. It may be stated thus:

"If the textile workers of America had been able to braid silk a little faster (or to be quite accurate a good deal faster), there would probably be no such phrase as 'wired wireless' in current radio speech to-day."

Do you see the point? Of course you do not, unless you happen to know the story. The application is quite simple, however, when explained; and Major General George O. Squier, known to every one as the originator of the wired wireless method, himself explained it at the outset of the paper in which he made popular announcement of his discovery. He tells us that the "key problem" in the procurement of essential Signal Corps supplies in the United States during the World War was the production of the necessary braiding machines for finishing insulated wire. The wire could itself be obtained; rubber insulation could be obtained; and there was no dearth of cotton thread for making the braid,—but machinery for braiding the thread was inadequate, and could not be rapidly supplied.




MAJOR-GENERAL GEO. O. SQUIER TESTING HIS WIRED-WIRELESS METHOD

The upper figure shows General Squier receiving messages from a lamp socket. The messages are transmitted by the wired-wireless system over an ordinary electric light wire. The lower figure gives a diagrammatic view of the receiving apparatus.

All the braiding machines in the United States in September, 1918, could produce the braided covering for only eight thousand miles of twisted insulated wire a month—and the American forces alone required forty thousand miles a month. And as if this were not bad enough, the allied council decided, on October 1st, 1918, that it would be necessary for the United States to furnish all of this type of wire used by the allied armies in the field, beginning March 1st, 1919; the estimated minimum requirement being one hundred thousand miles a month, or more than twelve times the capacity output of all the American machinery in existence.

Confronted with this situation, the United States Signal Corps, with General Squier at its head, not unnaturally realized the desirability of finding a substitute for braided cotton thread.

Thanks to the genius of General Squier, they found it. They found something not merely "just as good," but in many respects vastly better. Confronted with the shortage of braiding machines, General Squier said, in effect: "Let us try electron tubes instead." Asked to supply one hundred thousand miles of braided cotton per month, he said: "I will give you an unlimited quantity of electromagnetic waves instead."

And thereby hangs our paradox,—which of course, after the manner of paradoxes in general, proves to be no mystery at all when explained.

When General Squier was asked to provide wire for the entire allied armies, a piece of insulated wire must have looked as hateful to him as Cleopatra would have looked to Mark Antony had her nose been lengthened to the dimensions of a proboscis. But after the investigator had invoked the electron tubes and woven his web of electromagnetic waves, any piece of copper wire probably had in his eyes something of the beauty that the actual Cleopatra presented to the eyes of Antony.

Succinctly stated, what General Squire did was to run a

bare wire of phosphor bronze (number 18, such as is used for Signal Corps field antennæ) across the Washington channel of the Potomac River from the War College to the opposite shore in Potomac Park, letting it sink to the bottom and lie there absolutely unprotected. Not only was the wire not insulated, but pains had been taken to clean and entirely free it from any grease or other material that could in the least protect it. A standard Signal Corps radio telephone and telegraph set was directly connected to each end of the wire, one set serving as transmitter and the other as receiver. At the receiving end, the bare wire was directly connected to the grid terminal of an electron tube in the receiving set and the usual ground connection left open. Tuning the wire to a frequency of about six hundred thousand cycles a second, excellent telegraphy and telephony were attained.

"This experiment," says General Squier, "demonstrated the possibility of transmitting electromagnetic waves along bare wires submerged in water, and the use of an electron tube as a potentially operated device on open wire for the reception of signals."

That statement shows the characteristic modesty of the true scientist. For the simple experiment had really resulted in a fundamental discovery in science, foreshadowing the opening up of an entirely new department of radio science of almost inexhaustible possibilities. If, one of these days, you are able, sitting in your New York office, to take your telephone receiver off the hook and have a chat with a friend in London, it will be because General Squier was led (owing to the shortage of braiding machines) to find out whether he might not send a message along a bare wire under the Potomac.

### HOW THE MESSAGE TRAVELS

There are many interesting things to be told about General Squier's experiments, which include successful

tests of the bare wire as a transmitter of messages when laid along the moist earth, and even buried under the soil; but before we come to these, I want to consider the question as to how and why the electromagnetic waves follow the wire and are thus led to a definite goal, instead of radiating out into space and thereby being rapidly attenuated as in ordinary wireless transmission.

Let me say at once that the question can be answered only provisionally. We have to do with an extremely puzzling phenomenon. Only a very bold or reckless theorizer would have predicted, with any measure of confidence, results which were actually attained. Ninety-nine radio operators in a hundred would have dismissed the notion that a wireless message could be sent along a wire as absurd. The very phrasing seems contradictory. It is more than likely that General Squier himself was not overconfident about the success of his experiment. That his imagination conceived the thing as possible; and presently his ears told him that the possibility had become a reality. "Wired wireless" was an accomplished fact, whether or not a theory could be found to make it plausible.

The discoverer himself was content for the moment to go on with his experiment, avowing no theory by way of explanation. Doubtless that was the part of wisdom. Certainly it is better not to hamper a practical discovery by harnessing it too closely with theory at the outset. Nevertheless, no one can thoughtfully consider a phenomenon without at least attempting to form a mental picture of things that are happening along the course of the strand of copper wire that is so magically holding the electromagnetic waves in leash.

Of course it is not to be supposed that the electromagnetic waves travel in or even on the wire. By definition, these waves are undulations in the ether of space, which is supposed to be the universal medium, occupying the inter between the electrons that are conceived as the

ultimate particle of matter. According to one theory, the electron itself is only a whirl in the ether. In any event, the ether appears to ignore the very existence of matter, passing between the molecules of the most solid substance more freely than water passes through a sieve, inasmuch as there is no friction. The electromagnetic waves with which ordinary radio deals are not altogether unaffected by material substances, but to an amazing degree they appear to ignore obstructions.

As an illustration, we have just seen that the electromagnetic waves of General Squier's experiment followed the course of the wire laid along the bottom of the Potomac, apparently ignoring the presence of the water. Yet they obviously did not ignore the wire altogether—otherwise they would not have followed it.

It was not the wire itself, in all probability, that enchained the electromagnetic waves, but the electric field about the wire. An electric field, according to accredited theory, is merely the condition (of "strain" or what you will) existing in the ether surrounding an electron or group of electrons. When electrons are in transitional motion, their transit is manifested in what we term a current of electricity, and the motion of the electric field about them establishes a condition that we term magnetism. The moving electric field is apparent to the electromagnetic wave; so perhaps it is not strange that an electromagnetic wave in being should have affinity for the electric field surrounding a copper wire that chances to lead out from the source of its origin.

At first thought it seems odd that an electromagnetic wave should follow a bend in the wire; but we must reflect that the ordinary electromagnetic waves of ordinary radio do not travel in a right line, but follow the curve of the earth's surface. Possibly the electrostatic conditions of the lower atmosphere have to do with the course of the ordinary radio waves somewhat as the electric field about the wire has to do with directing waves of General

Squier's experiment,—the earth's surface itself representing, in this view, a magnified wire-surface. The familiar fact that radio messages are rapidly dissipated in the daytime, when the upper atmosphere is believed to be charged with electrons from the sun, possibly gives support to the analogy.

Let me repeat that all this is mere theory which the reader may find more or less satisfactory according to the bent of his mind; but which can neither add to nor detract from the force of observed facts to which we now return. The traditional apple falling from the tree on the pate of Sir Isaac Newton bruised the philosopher's pate neither more nor less because of the theory of universal gravitation.

### LATER EXPERIMENTS

The experiment of sending messages along the bare wire under the Potomac having thus succeeded beyond all reasonable expectations, a question naturally arose as to whether the experimenters might not have drawn a false inference from their observations. Might it not be that the portions of wire out of water at either terminal had acted as antennæ, and that the electromagnetic waves had passed directly through the air, as in ordinary radio transmission, or along the surface of the water?

To answer that question, the simple procedure was adopted of cutting off the main portion of the wire, leaving only the short aerial portion at sending and receiving stations, and a few feet under water. But now messages were no longer transmitted; and this negative result was very properly interpreted as demonstrating that the messages previously sent and received had in reality been directed along the wire.

Sundry other confirmative experiments having been made with a submerged wire, attention was directed to the possibility of conveying a directed message along a wire lying on the ground. A bare No. 16 wire was laid

on the surface of the earth connecting the main laboratory of the Signal Corps and a small field station one and three quarter miles distant. The radio telephone instruments used were standard sets utilizing an oscillating transmitter of the electron tube type. The transmitting current was about one hundred milliamperes, at any of the wave lengths available with these sets, ranging from about two hundred to five hundred and fifty meters. It was found that good telephone communication could be made with this equipment.

As the next important step in the series of experiments, the bare transmitting wire was buried in the earth to a depth of about eight inches. The bare No. 16 wire was laid in a plowed furrow and a second furrow plowed alongside completely covering the wire. The soil was moist, sandy loam, being only a few feet above tide water.

The wire thus buried conveyed the electromagnetic current as before and satisfactory communication was established for the distance of about a mile.

To make the experiment more definite, tests were made with the buried wire not laid in a straight line, but turning at various angles. Were the wire serving only as an ordinary antenna, it was reasoned, signals would be detected in the direction of a prolongation of a straight portion of wire; but in reality the test showed that signals could be detected best in close proximity to the wire itself in all its parts, proving that the electromagnetic waves turned the corners in order to follow the wire.

Although the soil did not prevent the passage of the message-bearing waves, it did exercise a curious influence, screening them or in effect preventing their escape from the region of the wire. Proof of this was found by moving an exploring coil along the line of the buried wire. The detecting instrument, held just above the surface, failed to reveal a signal; but when a short length of the wire was exposed by removing the earth, signals

were at once appreciable; and these disappeared when the earth was put back over the wire.

General Squier comments on the importance of this phenomenon from the standpoint of military usage. It is obvious that with a buried wire radio messages could be sent in secrecy, a desideratum well nigh impossible of attainment with aerial messages.

A successful termination of the experiments above described may be said to have established the principle of "wired wireless" beyond controversy. The importance of the discovery was so patent as to excite universal interest. Although the original tests had been made to meet wartime needs, it was clear that the new method would have abundant peace-time applications as well. The possibility of sending several messages along the same wire simultaneously at once suggested itself; and it was believed, with reason, that an adaptation of the message would make feasible the transmission of messages to and from moving trains.

As to both these, as well as to sundry other applications of wired wireless, I shall have something to say in a moment. Let it here suffice to note that General Squier, whose earlier experiments in multiplex telegraphy are well known, stated in his early report that the applicability of the new method to multiplexy was self-evident. It is obvious to any one familiar with the general principles of radio transmission that it should be possible, by using different wave lengths, to send several messages simultaneously in either direction along a single wire, each message indistinguishable except to the particular instrument tuned to receive it.

Practical experiment was presently to demonstrate the validity of this assumption, but in the meantime experiments designed to throw light on less patent features of the method were undertaken, particularly in the Signal Corps research laboratory at the Bureau of Standards. One object was to determine the electrical constance of

bare wire submerged in water when subjected to high frequency currents. At the Bureau of Standards a tank was available 125 meters long, 2 meters deep, and 2 meters wide. Two wires placed in the tank served as a to-and-fro conductor, constituting a complete transmission line immersed in water. Using an electron tube oscillator as transmitter, measurements were made to determine the apparent impedance of the system with the remote end short-circuited and also open-circuited. Even at the preliminary stages, the observations as to capacity and leakage of the wire were found highly interesting.

"It was seen," says General Squier, "that at low frequency the capacity is extremely large, about 1,200 microfarads per kilometer, the equivalent of an entire Atlantic cable, but the capacity diminishes very rapidly as the frequency is increased, and at a frequency of about 40,000 cycles per second, it practically vanishes. The leakage increases with the frequency up to about 5,000, and then begins to slowly decrease as the frequency is increased. The results were surprising, particularly the high capacity values at the low frequencies. The experiments apparently show that frequency of the current used has a marked influence on the behaviour as a medium, and is entirely different from what it would be for direct or low frequency current."

Tests of this character, while of great theoretical importance (and that means always, potentially of practical importance), have not the popular interest that attaches to the observations that were made by General Squier and his associates at an early stage of the investigation with the aid of resonance wave coils of various dimensions. The use of the coil was originally resorted to in order to secure high potential points at the receiving end of the line without losing the advantage of tuning, the circuit being open, and the grid directly connected to the line. Adjustment was obtained by sliding along the coil a narrow metal ring connected to the grid, this con-

stituting a capacity coupling between the grid terminal and the coil. Coils were made up of wave-lengths ranging from 250 meters to 1,800 meters.

One such coil, for example, was about four and a half inches (11.5 centimeters) in diameter and about twenty-three inches (58 centimeters) in length, with thirty-four turns of the wire per centimeter, and gave a fundamental wave-length of 1,700 meters.

This little instrument proved a veritable divining rod. Connected to an antenna or a bare wire in water or earth, as in General Squier's experiment, it not only can be used for tuning, but at the same time wave development on the coil permits a test of the highest potential point, or point of greatest sensitiveness. More than that, the resonance wave-coil can be substituted for the ordinary antenna, itself constituting a complete antenna system. The coil may be grounded at one end or it may be entirely free. In either case it may be utilized to receive radio signals.

"It may be noted," says General Squier, "that in an antenna of this kind all the electrical constants, inductance, capacity, and resistance and the electro-motive force induced in it by the incoming signals are of a distributive character, which makes it in a sense an ideal wave-conductor."

Even that does not tell the entire story of the little resonance coil. The discovery was presently made that it possesses also remarkable directive properties.

If the coil is turned about, so that its position in relation to the direction of the electromagnetic waves of ordinary radio is modified, there is a constant change in the voltage and current distribution on the coil, and a corresponding shift in the position of the point of maximum potential.

If the coil is held at right angles to the direction of the transmitting station from which the electromagnetic waves are coming, these waves beat evenly against it, as

will be obvious, and so produce a condition of uniformly distributed electrical constants. There is a point of maximum potential, varying somewhat with the length of the coil, frequency, and terminal conditions. But this maximum may be determined by moving the terminal of the grid of an electron tube along the coil.

In practise a narrow metal ring that would slide freely along the coil is used. But if now the coil is turned to point more or less in the direction of the transmitting station, so that the electromagnetic waves come against it slantwise, the point of maximum potential shifts, owing to the difference in time at which the waves strike different parts of the coil.

Here, then, is a direction-finder comparable to the familiar looped antenna, which can be so turned as to reveal the plane in which the electromagnetic waves are moving. But the resonance coil goes beyond this, for it was found that when it is moved about until its longitudinal axis is parallel to the direction of the electromagnetic waves (in other words, until it is pointed toward the transmitting station from which the waves emanate), the potential maximum loop, which has shifted along the shaft of the instrument, is duplicated by another loop of substantially the same amplitude at the opposite end of the coil.

If now the pointing instrument is moved about a little, so that its axis is slightly out of parallel with the waves, it will be found that the potential loop at one end has greater amplitude, and that this is the end pointing *toward* the transmitting station,—the north-seeking end of the compass needle, so to speak.

Evidently, then, manipulation of the little wire-wound divining rod, held in the hand and tested with a sliding ring connected with the receiving grid, makes it possible to determine the direction of the transmitting station from which the signals proceed,—a matter of tremendous significance, as no one needs to be told. A looped aerial

used, let us say, in Baltimore does not tell whether the message comes from Philadelphia or Washington. But the magic coil gives the answer.

The discussion of the necromantic activities of the little resonance coil has carried us for the moment somewhat far afield from our subject of wired wireless. Perhaps this is not inexcusable, since it was wired wireless experiments that led to the investigation of the resonance coil. But in any event we shall now return to our subject proper, and consider the more recent developments and potential applications of General Squier's remarkable discovery of the possibility of directing electromagnetic waves of radio frequency along naked wires.

## THE "SUPER-PHONE"

Among the immediately possible applications of wired radio having genuine significance from the standpoint of the public at large, one of the most interesting is that associated with what has been termed the "super-phone." As the name implies, this refers to the application of the Squier method to the general telephone service; and the merit of the method is that it can be applied in connection with the ordinary telephone equipment that is in almost every household and business office in the land.

The investigations leading to this application of the Squier method have been made at the Bureau of Standards. A compact, semi-portable apparatus has been devised, weighing only about forty pounds, which contains a complete transmitting and receiving radio equipment, susceptible of use for direct radio; yet which may be promptly attached to the wires of an ordinary desk telephone, and thus utilized for the sending and receiving of messages directed along the ordinary telephone wire.

The messages thus sent differ from ordinary telephone messages in that they are generated in the radio apparatus by a high frequency current, and are conveyed

along the telephone wire (but not in or on the wire itself according to theory) as electromagnetic waves of predetermined and carefully regulated length, closely similar, according to one view at any rate, in their general

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MAJOR GENERAL SQUIER (AT LEFT) TESTING THE WIRED-WIRELESS SYSTEM

The "super-phone," a development of wired-wireless, permits the transmission of messages over the ordinary telephone wire on high-frequency carrier waves that are inaudible until interpreted by the radio receiver.

character and speed of progression to the electromagnetic waves of ordinary direct radio.

Differing thus fundamentally in character from the audio-frequency electrical pulsations that are passing along the wire, these radio-frequency waves of the super-phone do not interfere with the ordinary telephone message. Communication of the ordinary type may be carried on along a telephone wire at a time when not

merely one but several of the wired-wireless messages are passing in either direction or in both directions simultaneously.

It is, of course, necessary that a super-phone message shall be received at the other end of the line with the aid of a radio receiving apparatus, tuned to the frequency of the transmitting apparatus. Both transmitting and receiving radio apparatuses, however, may use the small, compact, induction coil perfected by General Squier in the course of his experiments, thus doing away with the need of cumbersome antennæ.

Thus it appears that if two persons wish to communicate with each other over an ordinary telephone line, and to obviate the possibility of any one "listening in," one may call the other in the usual way, and then each may attach at his end of the line a super-phone radio apparatus, and the conversation may go on indefinitely; there being no interference with the ordinary use of the telephone wires meantime, and no possibility that the conversation will be overheard. If dual transit of messages is approximately simultaneous, it is of course necessary to have separately tuned sending and receiving apparatuses. The waves to be utilized, being compacted along the channel furnished by the wire and thus prevented from dissipating their energy, permit communication to be effected with a relatively low power from the apparatus. Voltage for voltage of generating battery, it has been estimated that the directed-radio super-phone message has a carrying power twenty times that of a direct radio message.

The conservation of energy in transmitting messages is, indeed, one of the merits of the Squier system. A moment's reflection makes the explanation clear. Ordinary radio waves radiate from the aerial in every direction with almost equal intensity, the aerial having only slight directional power. The intensity of the waves decreases as the distance. At one mile from the aerial,

the radio wave coming that way compares in intensity with the same wave at a distance of one rod from the wire as 1 compares to 320. At five or ten or fifteen miles away, the attenuation is expressed in figures that seem merely ridiculous rather than comprehensible.

But this principle does not apply to the shaft of carrier waves passing from the radio transmitter along the telephone wire. These are held in a tubular channel and thus kept together, very much as the sound waves in a speaking megaphone are held together so that the voice has apparently enhanced amplitude and far greater carrying power in a given direction.

So important is this principle, that it has even been suggested that it may be possible to transmit significant quantities of energy by wired wireless, thus fulfilling the dream of Tesla, which hitherto has seemed impossible of realization. That, however, is a possible development of the future. Here we are concerned with the line-radio realities of the present.

Of course the use of the super-phone, as just described, calls for radio equipment at either end of the line. But this equipment need not be very cumbersome; nor need it be very expensive.

Doubtless when the method is perfected, it will be possible to have both transmitting and receiving mechanisms in very compact form, like the simpler direct-radio outfits that have attained such popularity. Indeed, there is no apparent reason why the direct-radio outfit of the amateur cannot be adapted for super-phone use. This would imply, of course, the installation of a transmitting set, which the ordinary amateur does not have; but the difference between receiving and transmitting apparatuses of the vacuum-tube type (the only kind of transmitter that concerns the amateur) is not great; and the possibility of using the transmitter in connection with the ordinary telephone line will put an entirely new aspect on the problem of amateur radio transmission.

So long as direct radio only is in question, radio transmission by amateurs in general is not permissible. If even a tenth of the present receivers were to attempt to send, under necessary restrictions as to wave lengths and present difficulties of accurate tuning, the air would become jammed, to the obliteration of all radio communication. But if the telephone wires were used to convey the radio messages, there is no such difficulty; and it may reasonably be expected that when the super-phone method is commercially available, a radio transmitting apparatus will become part of the regular equipment of the amateur who now uses only a receiver.

### LINE RADIO TO AND FROM MOVING TRAINS

Meantime experimental work has extended to the application of the wired-wireless method to a field where, rather curiously, modern methods of communication have not hitherto been available at all. The radio apparatus has been installed in railway cars, to test the feasibility of telephonic communication via the telephone wires that stretch everywhere along the track.

The project of sending messages to and from a moving train is not a new one. As long ago as 1885, or thereabouts, Thomas A. Edison invented and patented a method by which telegraphic communication could be held between a moving train and a distant station; the principle involved being that of electrostatic induction between the wire and especially constructed condensing apparatus. The method appears to have been a scientific but not a commercial success. It remains to be seen whether the present-day public feels greater need of keeping in touch with its home and office while making railway journeys than did the public of a third of a century or so ago.

It is a question for the public to decide, inasmuch as the experimenters have proved that intercommunication is quite feasible both by wired radio and direct radio

methods. Our concern at the moment is with the former, but for purposes of comparison we shall consider the other method as well.

It will be recalled that General Squier first became known to the public at large through his practical and highly successful experiments in multiplex telephony and telegraphy. Technical publication of his results was made as long ago as 1911. The methods that he then introduced consisted of the use of the high-frequency current, with tuned circuits and a detector or rectifying at the receiving terminus. The telephone and telegraph companies recognized the success of these experiments, and long distance lines employing the system are in operation between a number of large cities. The method has also been extensively adopted in foreign countries, including Japan.

It was quite natural, then, that General Squier should return to this field of his earlier triumphs. The new experiments inaugurated in the autumn of 1919 had to do with communication between a station installed in a car standing on a track of the New York Central Railway and another placed in a moving train running between New York and Albany. Between the radio outfits on the cars and the telephone wires along the track, there was of course no direct contact.

The experiments were entirely successful, telephonic communication being established and kept up between the stationary car and the moving train to a distance of ninety miles. The telephone conductors paralleling the railroad tracks served as the path for the "carrier-frequency" current. According to the description of Mr. R. G. Duncan, Jr., who actively cooperated in the experiment, "the transmitting and receiving apparatus at the fixed station were connected between one aerial wire and the ground; at the receiving station the apparatus was connected to a closed loop, properly orientated with respect to the telegraph wires. The transfer of energy from

the elevated wires to the loop, or vice-versa, is affected by the inductive action of the electromagnetic field."

Although these successful experiments have been described as part of the triumph of wired-wireless, it is not quite clear that they belong to the same series of phenomena with the famous tests with bare wires under water and under ground along which electromagnetic waves appeared to be transmitted. When electromagnetic induction occurs between one wire and another, the current generated in the second wire is an electric current which may develop electromagnetic waves under certain conditions of inductance, resistance, and capacity, but which in itself is thought of in terms of moving electrons rather than in terms of waves in the ether.

It might be argued, then, that in the experiment just recorded, an electric current is set up in the telephone wire by induction; and that the wire conveys this current directly, and transfers it inductively to the receiving apparatus of the stationary car, with no question of an antenna effect and the generation of electromagnetic (radio) waves.

In that view, the new train experiments would differ from the older ones of Mr. Edison, and from many interesting experiments in electrical induction between telegraph wires at a distance performed in the pre-radio days, notably in England, chiefly in the type of electric current used. A significant difference, to be sure, but not a difference denoting the introduction of a fundamentally new principle. In a word, the moving train experiments would appear to be a culmination of General Squier's earlier discoveries in multiplex telegraphy and telephony, rather than an extension of his work with the newer type of wired-wireless.

### DIRECT RADIO FROM TRAINS

Whatever the validity of this suggestion, however, the experiments have great interest; and the utilization of

a far-reaching induction field,—in itself one of the most mystifying of phenomena, however commonly it may be observed,—seems to give the experiment kinship with radio whether or not electromagnetic waves are in question.

Meantime these successful experiments were probably responsible, in part at any rate, for the reestablishment of tests as to the feasibility of direct radio telephony between a moving train and distant stations. Such tests had been made originally as long ago as 1914 by the Delaware, Lackawanna, and Western Railroad with a view to the establishment of a regular radio service. Even at that time, the tests had a measure of success. With the great progress of radio telephony in the intervening period, it could confidently be predicted that present-day tests would be even more successful. The results of the comprehensive experiments undertaken in recent weeks amply justify this expectation.

The new experiments of the Lackawanna railway were begun in March of the present year. They have been continued under supervision of Mr. David W. Richardson, of Princeton University, in association with Mr. G. D. Murray, Jr., and Mr. Edgar Sisson, Jr. The first tests, having to do with receiving only, were carried out on the short run to Morristown, N. J. A temporary one-wire aerial was adjusted above a single car, and the receiving outfit consisted of a regenerative circuit with detector and two-step amplifier. Then another temporary aerial was installed on two 70-foot cars, and a 15-watt radiophone transmitter was tested.

The messages were heard nine miles from the car, and the receiving results were remarkable, the loud speaker making messages audible throughout the car; proving that very satisfactory reception was possible with low aerial, only six inches above the top of the car.

Subsequently a buffet car was equipped with three four-and-one-half inch six-wire cages, one on each side

and one in the center. The same 15-watt 'phone set was installed. The car was placed in the Lackawanna Limited and tests were made all along the route, from sea level to an elevation of 2,000 feet, and under widely varying conditions of local topography. It is of especial

RADIO FROM A MOVING TRAIN

Messages are being transmitted and received by radio, regardless of the train's motion, and interesting tests made of the relations of topographical conditions to the progress of radio waves.

interest to note that inside the Bergen tunnel, which is 4,283 feet long and 90 feet underground, one or two continuous wave stations and several ships were heard distinctly. Upon emerging from the tunnel, however, signal strength increased with a "bang."

Again it was noted, in a tunnel several hundred feet long near Scranton, that a message being received was hardly interfered with. On the other hand, a steady

radio conversation that was being carried on with a Scranton radio station was suddenly cut off altogether, about twelve miles out, when the track curved in such a way that a mountain intervened; and, this conversation was not resumed until the train had ascended to a large lake.

Interference from a mountain was what might have been expected; and in general it is reported that current theories as to interferences were for the most part confirmed, except that the immediate proximity of rock, steel bridges, and of bodies of earth of less than mountainous dimensions, did not obstruct the messages as might have been expected. Very little difference could be noted whether the railroad ran through a deep cut, thirty or forty feet deep, or was on the level.

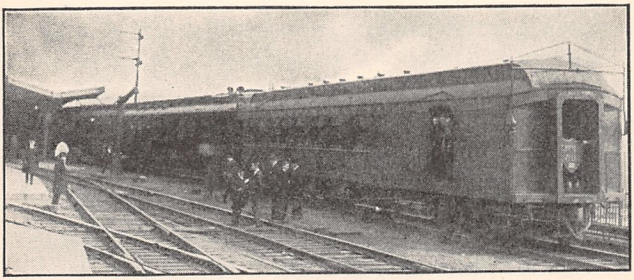
Whenever the train went through a thickly wooded piece of land, however, where the trees were high, all long-distance signals faded out entirely.

On the other hand, the proximity of a body of water, even a small stream, seemed greatly to increase the signal strength.

Pronounced directional effect of the aerial was noted in receiving. Often when the train went round a curve, on perfectly level ground, one set of stations would fade out and another would be heard,—the audible stations being always the ones toward which the aerial pointed. This, of course, confirmed previous experiences. It will be recalled that when Mr. Paul F. Godley made his famous trip to Scotland last winter to prove that American amateur short-wave signals could be interpreted across the ocean, he was careful to rig up his 1,300 foot aerial "heading directly toward Chicago." Incidentally, it may be recalled also, that this wire was adjusted on 12-foot poles, and so was at approximately the elevation of the railway aerial of the Lackawanna experiment. The idea that the receiving aerial must be at a great elevation is a

misconception that such observations will help to dispel. In the same connection, it may be recalled that Dr. Taylor, of the University of North Dakota, receives messages from Europe in one direction and Japan in another with an antenna (properly insulated) lying along the ground.

On the other hand, it should not be overlooked that Mr. Godley selected a broad level tract for the erection of his aerial, and that Dr. Taylor operates in the midst



A TRAIN EQUIPPED FOR RADIO WORK

The antenna stretched across the top of the car was proved to work efficiently. Directional effects were observed as the train went about curves.

of a plain. Local conditions in a hill country or a wooded region may make it very desirable to elevate the receiving wire. In any event, the amateur may advantageously pay more attention than he usually does to the topographical conditions of his immediate environment. To supplement what has just been recorded, it may be added that in the Lackawanna experiments, Mr. Richardson reports that the best reception-strength of all was observed when passing on a high embankment across a bare plain. This seemed even better than the proximity of a lake.

THE NEWEST APPLICATION OF THE SQUIER METHOD

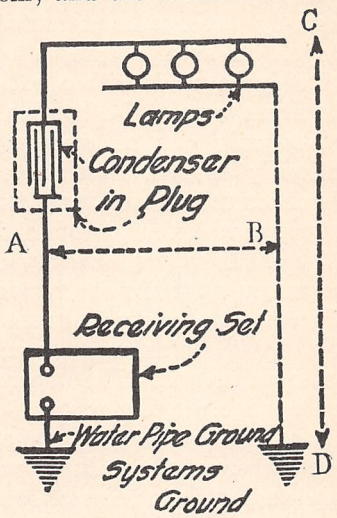
All this refers, of course, to direct radio, and therefore carries us somewhat afield from the Squier method, to which we now return.

General Squier's newest triumph is the demonstration that line radio may be adapted to broadcasting by utilization of ordinary electric light wires. The experiment in which he hitched his receiving radio telephone to the socket of an ordinary electric light on his desk, and listened to music broadcasted from a distant station in the Munitions Building, was given wide publicity in the newspapers and need not be dealt with *in extenso* here. A few words of explication, however, are perhaps to be desired, in view of a popular misconception that has arisen.

It appears not to have been understood by all who have written about this new achievement of General Squier's, that the electric wire cable is used only to direct the "broadcasted" message, as a telephone wire directs ordinary line-radio conversation. The electric light wire is not functioning as an aerial. It does not catch up signals from the ether, but only conveys messages—lectures, music, or what not—sent directly from a transmitter in the power house; the transmitting apparatus being connected to a socket, just as is the receiving apparatus at the other end of the line.

It would appear that such use of an electric light system offers at least one solution of the broadcasting problem. To illustrate: In most village communities, the electric light goes everywhere. Concerts and other entertainments could of course be heard by line radio wherever the electric light system is installed. Half a dozen different programs could be sent at the same time along the wire, by using different frequencies. It would thus be possible for each household to select the particular entertainment that it wished to hear.

It would be possible, apparently, to have different entertainments in various rooms of the same house. Father could listen to the sporting news in his study; mother to a concert in the sitting room; and the children to some juvenile entertainment in the play room. Meantime people whose houses are not supplied with electric lights might gather in various public halls, say schoolrooms and churches, to listen to entertainments of various types. The possibilities of the method seem limitless.




THE LIGHTNING-PLUG AERIAL

The method of using the electric light wires in place of ordinary aerial was probably suggested by General Squier's wired-wireless experiments. Several types of condenser plugs have been devised, to obviate danger from the electric light current. In many cases, the method appears to work satisfactorily; but it does not ordinarily take the place of the conventional antenna system.

In the light of such feasible applications of General Squier's method, the question as to whether the method is technically "line-radio" or "high-frequency telephony" seems altogether trivial. The essential thing is that the method permits any sounds whatsoever to be transmuted into radio-frequency vibrations and sent along a wire, and at the receiving end reduced to audio-frequency and rectified and amplified, using the ordinary radio apparatus.

For example, General Squier has made a very interesting demonstration in which the heart beat of a patient

was sent by line radio to a distant amphitheater and trumpeted with a "loud speaker" so that an audience of physicians could hear the sounds far more distinctly than any single member of the group could have heard them by direct examination of the patient with a stethoscope. In such a case, a better diagnosis might conceivably be made with a patient miles away than if the physician were at the bedside.

Not only can all sounds be thus transmitted, but, curiously enough, with line radio the voice suffers less distortion than if sent by ordinary telephone. This seems utterly paradoxical, but is not inexplicable.

The radio waves, as every one knows, are of such high frequency as to lie far beyond the range of audibility. The current that produces the 200-meter waves generally used by the amateur, for example, oscillates 1,500,000 times per second. The upper limit of audible waves, for the average ear, is perhaps 10,000 oscillations per second. Waves of a few hundred cycles per second represent ordinary tones of the talking voice. There are, however, overtones or harmonics of several times the fundamental frequency, and these become a disturbing influence in the ordinary telephone conversation, due to the fact that the tones represented by more rapid pulsations encounter greater resistance than the lower ones in the telephone electric circuit.

Mr. S. R. Winters, in illustrating the advantage of wired wireless, uses by way of illustration a hypothetical case in which a certain voice tone has a fundamental frequency of 250 vibrations a second, with overtones of 1,250 vibrations. The frequency of the harmonic is, then, in this case, five times that of the fundamental.

But now if these tones are used to modulate a high-frequency current, or so-called "carrier" current of, let us say, 150,000 oscillations, the fundamental tone impressed on the high-frequency current is represented by 150,250 vibrations, and the overtone by 151,250, a difference not

of five hundred per cent as before but of only six-tenths of one per cent, the net result being that the high-frequency current conveys the entire range of voice modulations practically undistorted, and restores them, through the aid of the receiving radio mechanism, to audio-frequency, with far greater fidelity than is feasible when the ordinary slow-frequency current of wire telephony is the medium of transmission.

Such are some of the advantages inherent in the nature of the high-frequency current. The present-day perfection of long-distance telephony is largely due to the utilization of this current; with apparatus for rectification, reduction to audio-frequency, and amplification essentially similar to the mechanism of the radio receiving telephone—each being dependent on that most marvelous of devices, the DeForest audion, or three-electrode vacuum tube.

A word about multiplexing—the sending of several messages at one time over the same wire. This is accomplished, just as in direct radio, by using transmitting current of different frequencies. As experiments have been made with currents ranging from 5,000 to 500,000 cycles per second, there is obviously ample opportunity for discrimination. It is said that in practical operation it is desirable to have a difference of at least 3,000 cycles between the various currents.

In duplex telephony—the sending of messages in opposite directions at the same time, as in a conversation—the same system of course obtains. Curiously enough, it is reported that greater difficulties are encountered here than in multiplexing. Two messages on the wire at the same time may develop a "beat" or autodyne effect, suggesting that the electromagnetic impulses involved are radically different from the electromagnetic waves of direct radio, between which there is no such interference. The "beat" effect utilized in the reduction of radio-frequency currents to audio-frequency in direct radio is

a phenomenon of the vacuum tube, as is well known, and has no direct relation to the electromagnetic waves that brought the message to the receiving antenna.

Thus again we are led to a question of theory; only to be again reminded of its triviality. The practicalities of line radio are matters of fact, and important matters of fact, of present-day experience. And there is every probability that the method introduced by General Squier will prove to have a larger measure of utility in the near future than even enthusiasts have predicted; not in any sense supplanting direct radio, but supplementing it in important fields of mutual action, and taking full possession of other fields where direct radio does not offer competition.

Call it by what name you will, the Squier method bids fair to prove itself one of the greatest triumphs of applied science of our wonderful generation.

## CHAPTER XII

## RADIO CONTROL OF DISTANT APPARATUS

AT the radio convention held at the Hotel Pennsylvania in New York City in March, 1922, no other exhibit attracted anything like the popular attention bestowed on Mr. E. P. Glavin's miniature automobile controlled by wireless.

Several times each day the central floor of the exhibition hall was cleared, the crowds of eager observers being held back by a rope stretched across the room, in order that Mr. Glavin might bring forth his strange vehicle and put it through its mystifying paces. I use the word "mystifying" advisedly, even though there is no secret as to the way in which Mr. Glavin accomplished the wonder. A wonder it remains, even after the fullest explanation is given that the inventor himself or any one else can provide. The greater your knowledge of radio, the more fully you will agree to that proposition.

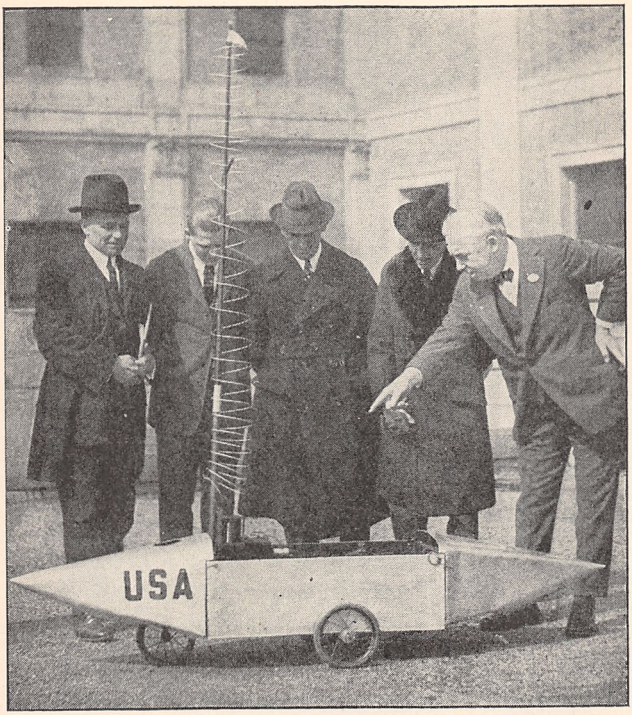
You see Mr. Glavin standing at the side of the room, a solid-figured man with gray hair and a strong, thoughtful type of face, and you are at once struck with his resemblance to that other wizard in the field of electricity, Thomas W. Edison. The little automobile, somewhat boat-like in shape, and with a mast that heightens the resemblance, stands in the middle of the floor, a prosaic enough vehicle, the metal covering of which might give the idea that it is a model of some new type of military armored "tank." Your only clue to its real character, if you are at a little distance, is supplied by the coil of wire that ascends as a spiral, about five or six inches in

diameter, winding about the mast to its top, where there is a little electric signal light. On closer inspection, you might see within the open body of the vehicle a series of electric batteries and sundry mechanical devices the observation of which would probably make you not much the wiser, even if you are a skilled mechanician. About the only obvious thing is that, in addition to the other wheels of the vehicle, there is a central wheel, the rim of which projects into the body of the little car, to which the propelling mechanism is attached. The single front wheel, it may also be noted, would serve to guide the vehicle to left or right, just as a bicycle is guided. But there is no bicycle or other mechanism observable by which the wheel might apparently be turned.

Mr. Glavin, standing there with thoughtful mien perhaps twenty feet away from the car, raises his hand. You note that the signal light at the tip of the mast flashes, but nothing more tangible happens. Another slight motion of Mr. Glavin's hand. Now the car starts forward, and begins its strange journey. It passes along the hall at a moderate pace, like a tank leisurely charging the mass of spectators crowded against the rope; but before it reaches them it circles to the left; and moves back toward the starting point. Mr. Glavin's hands are impassive, but from time to time he lifts his hands with a little movement as of salutation; and each time that he does this you will note that the car changes its course. It circles to right as well as left, cutting a big eight, and taking in first and last the entire available roadway. With seeming intelligence it turns its prow just in time to avoid collision with the spectators at either end of the exhibition floor or the pillars and exhibition booths at the side.

I chanced to be standing beside Mr. Glavin on one of the occasions when the car was making such a journey. "Now I will have it come around and stop right in front of us," he remarked quietly. A wave or two of the hand,

and the thing was done. It was hard to avoid the feeling that this weirdly responsive little vehicle, as it circled about and came toward us and stopped respectfully four



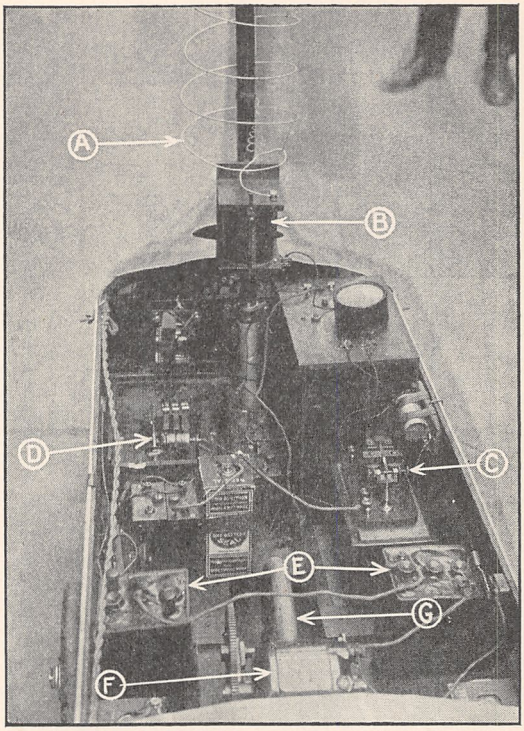

MR. GLAVIN'S RADIO CAR

The inventor, Mr. Edward P. Glavin (at the right), worked nine years at the perfecting of this car, which responds to radio signals. The power for driving the car is supplied by local batteries.

or five feet away, was manifesting actual intelligence and consciously responding to the mandate of its master.

There was a time when an exhibition like that would have been labeled "wizardry," and an interpretation put

upon the word that would have boded ill for the exhibitor. The word "wizardry" still applies, but it now has scientific instead of superstitious implication. The




Courtesy "Popular Radio."

DETAILS OF CONSTRUCTION OF THE GLAVIN RADIO CAR

"The essential working parts, by means of which the vehicle is controlled, are as follows: A is the spiral antenna; B is the tuning coil; C is the sensitive relay operated by the feeble radio currents; D is the control switch which is set into action by the closing of the contacts of the relay; E are the storage batteries which furnish the electrical power to the motor F, and G is the propelling wheel."—Courtesy of *Popular Radio.*

medieval interpretation would have condemned the inventor for consorting with evil spirits; the modern interpretation explains that he is juggling with electromagnetic waves in the ether.

There is, as I have said, no mystery about the *modus operandi* of Mr. Glavin's achievement. Every observer is aware that the little car makes its pilgrimage under radio control. Every one knows that when the director lifts his hand he is merely signaling to the radio operator across the room, who will touch a telegraph key connected with an ordinary transmitting apparatus operating in connection with a short two-wire aerial that is strung across the hall up toward the ceiling. Every one knows that the electromagnetic waves sent out from the aerial are caught up by the receiving coil that is spiraled to the mast constituting a receiving antenna, and that it is the impulse thus coming to the radio apparatus stored within the body of the little car that determines its movements.

But I repeat that this knowledge does not take away the mystery. To see that little vehicle, under no man's hand, start and move about in an intelligently directed path, and stop, and start again, and finally make its way to the booth that is its temporary home, and stop there,—quite as a horse makes its way to its own stable,—is to witness a scientific miracle that yields place to few others in genuine mysteriousness. The builder of radio apparatus can tell how the thing is done in mechanical terms. The mathematician can calculate the energy involved. But no man can give what could properly be called a full explanation of the mystery.

It is possible, of course, to go a little more into detail as to the precise steps of the series of processes by which a wave of the hand appears to be translated into the propulsion of a vehicle,—not only appears to be, but really is so transplanted, if we accept words in their proper meaning. I have already explained the sequence of events immediately following the wave of the hand. It

remains to say something as to what takes place within the mechanism of the vehicle when the wireless impulse is received from the transmitting aerial.

At the outset, it must be understood that the radio waves which determine the activities of the little car do not supply the energy of propulsion. By no possibility could they do that. The electromagnetic waves that come from the aerial could no more turn the driving wheel and propel the vehicle along the floor than could the same feat be accomplished by those other electromagnetic waves termed waves of light which pass from Mr. Glavin's hand to the eye of the operator of the radio-telegraphic key. The radio waves convey more energy than the light waves, to be sure; but by no conceivability could they convey enough energy to propel a vehicle weighing eight pounds, let alone eight hundred.

Most of the observers are well aware of that. They understand that the actual propulsion of the wireless car is effected by a storage battery which is a part of the internal mechanism of the car itself. A little dynamo, differing in no essentials from the ones that propel other electrically driven vehicles—from automobiles to trolley cars—metamorphoses the energy of the storage battery to energy of molar motion, and turns the wheel. The electromagnetic waves from the aerial have only the function of the motorman on the trolley car throwing the electric current in or out of circuit.

It is the way in which this is accomplished, however, that constitutes the very essence of Mr. Glavin's invention.

The statement just given perhaps does not do full justice to the problem. It was necessary not merely to throw on and shut off current, enabling the car to start and stop (that being all that the motorman on the trolley is called upon to do), but it was necessary also to provide for the lateral guidance of the car, a duty of which the motorman is relieved by the railway irons. The

feat of Mr. Glavin's radia-automaton might better be likened to the task of the automobile driver, who not only starts and stops his car but turns it to right and left.

If you think a little on this problem, you will not be surprised to learn that Mr. Glavin labored with it for nine years before he solved it to his entire satisfaction. The inventor himself would probably qualify that phrase and say that he labored nine years before he got the car to operating as it now does, and that even now he feels that he has only made a tentative solution of the problem, and is by no means satisfied with it as an ultimate achievement.

Be that as it may, the present achievement is notable enough to satisfy most inventors, and to excite the wonderment of all beholders. The mechanism involved, so Mr. Glavin assures us, is relatively simple. Important mechanical devices almost always are simple when perfected. In this case, the mechanism that shunts the current from one circuit to another consists of a small drum actuated by an electromagnetic dog-and-ratchet arrangement. Released by one signal, the drum rotates sufficiently to bring a certain brass collar in contact with the poles of the battery, establishing a circuit that lights the electric lamp at the top of the mast head. A second signal releases the drum and permits it to turn into the next position, where another brass collar establishes the circuit that enables the dynamo to actuate the propelling wheel. The motorman has turned his lever and established the circuit and the car is in motion. Now comes the third signal, and this (while leaving the propulsive current in circuit) permits another shift of the drum, bringing into action an electrically driven power that turns the guiding wheel to the left. The car will now circle to the left until the next signal shall bring the wheel back again; and then it will go straight ahead again until the sequential signal turns it to the right.

There are twelve signals in the entire series, and the

successive shifts of the drum necessarily take place in an unvarying sequence. Straight ahead—turn to the left—straight ahead on a new tangent—turn to the right—straight ahead on a new tangent—turn to the left—and so on. There is no way of changing the succession of the signals.

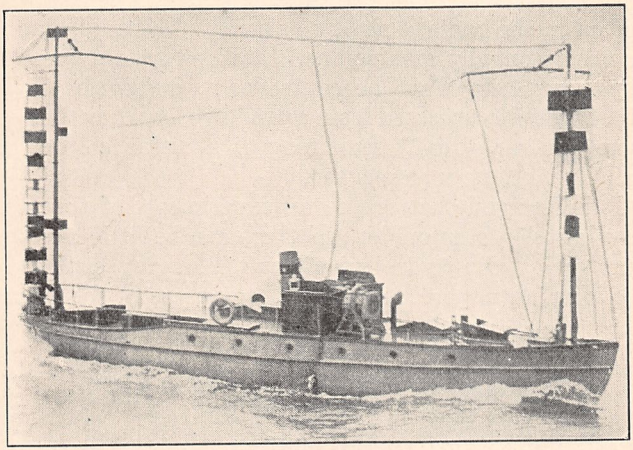
Nevertheless, the car can be made to take any desired course—just as the man-driven automobile can do. If Mr. Glavin wished the car to make its first turn to the right instead of to the left, he would merely give three signals in rapid succession after the vehicle is under way. The three signals can be given in less than a second's time; with the result that the drum will shift so rapidly by the left-turn circuit and the back-to-center circuit that before the wheel has fairly begun to respond, the turn-to-right circuit is operating. In other words, the undesirable signals were "jammed" and rendered inoperable.

Such, then, are the essentials of Mr. Glavin's invention. In a sense it is simple, yet I repeat that the explanation leaves one full of wonderment. Of all radio marvels, few are more thought-provocative than this.

### RADIO-DIRECTED WATERCRAFT

Mr. Glavin's car is an original invention, and in itself a very novel and interesting craft. But of course the principle of its operation is not altogether novel. It will be recalled that Mr. John Hays Hammond, Jr., a number of years ago, produced a very small vehicle under wireless control, and in particular became known for the application of the principle to motor-driven boats. The experiments, conducted under official surveillance, in which he demonstrated that a screw-propelled craft of considerable size could be navigated from the shore and caused to go through any desired maneuvers at any distance within the range of vision, were widely commented on.

At the outbreak of the war, it was expected by many persons who were aware of Mr. Hammond's success in the radio control of watercraft, that small boats, and in particular torpedoes, would be thus directed in actual naval engagements; but it does not appear that such anticipations were realized.



THE RADIO-CONTROLLED BOAT OF MR. JOHN HAYES HAMMOND, JR.

This boat responds to radio signals, maneuvering as if controlled by a local pilot. The power for propelling the boat is of course supplied locally. The radio signal serves merely to release controls, like the trigger of a gun.

After the war, however, when experiments with bombs dropped from aircraft and other missiles directed against a moving ship were undertaken by the government, a spectacular test was made in which the old battleship *Iowa* was used as a target. This ship was caused to maneuver, with no one on board, under radio guidance directed from a ship several miles distant, in order that the bomb-dropping test might be made. The feasibility of thus controlling a ship of large size, driven of course

by its own engines, but controlled as to its direction of movement—maneuvering to right or left, stopping, or what not, precisely as if guided from the bridge in the ordinary way—constituted a demonstration that can hardly fail to lead to practical applications of the method in future.

Even more interesting are the experiments recently reported in the radio control of aircraft. There appears to be no reason why an airplane, stabilized by a gyroscopic apparatus, might not be controlled and directed in its flight by radio operated from a land station or, better yet, from another aircraft remaining at a distance from the craft being thus manipulated.

It is reported that successful experiments of this kind have already been made; and there can be little question that such radio-controlled aircraft, carrying explosives, will play an important part in the warfare of the future.

## SENDING PICTURES BY RADIO

All this, as previously pointed out, involves nothing more than the designing of mechanisms that are, in effect, held in leash, to be released by a radio signal, somewhat as the hammer of a gun is released by touching the trigger. The radio waves do not transmit a significant quantity of energy, but they can readily transmit a sufficient amount to cause the release of a trigger—as the fundamental experiment of operating a telegraph key sufficiently demonstrates. Therefore there would appear to be no limit whatever as to the types of mechanisms that might be controlled from a distance by radio waves. It is necessary, of course, to have the receiving mechanism tuned in such a way as to respond to a particular wave only. That being accomplished, a mechanism may be held temporarily in leash, its potential power inoperative, until the right signal is transmitted; and then it will

respond, just as Mr. Glavin's car does, and just as the *Iowa* did, merely by utilizing the power stored in local batteries or steam engines or any other power that may be stored and brought into action by the release of a safety-clutch.

There is one type of radio-direction of apparatuses from a distance, however, which has to do with so different a field of action that it may seem at first glance to involve quite different principles. I refer to the transmission of pictures by radio.

This mystifying feat has been accomplished by the utilization of at least two methods that differ quite radically in method; yet there is after all no fundamental diversity of principle involved. The electromagnetic waves used in radio convey a small amount of energy, capable of setting up the kind of commotion in a wire that we call an electric current. Radio amplifying apparatus can magnify this current; or rather can utilize a locally developed current to enhance the effect of the signal currents. All our studies of radio have to do with phenomena of this type; and in considering the transmission of pictures, or, to speak more accurately, the reproduction at a receiving station of pictures manipulated at a sending station, we have to do merely with another illustration of the same thing. Only now the radio receiving and transmitting apparatus is supplemented by particular types of mechanism adapted for the new purpose.

The essential new mechanism in all the types of picture-transmitting apparatus hitherto developed is a revolving cylinder, similar to that of the older style of phonographs or the cylinders used in the dictating machine of the dictaphone and ediphone type. Transmitting and receiving mechanisms are equipped with cylinders of precisely the same size, synchronized to revolve with absolute uniformity.

In one type of machine the picture to be transmitted is etched on a metal surface, so that the lines or dots repre-

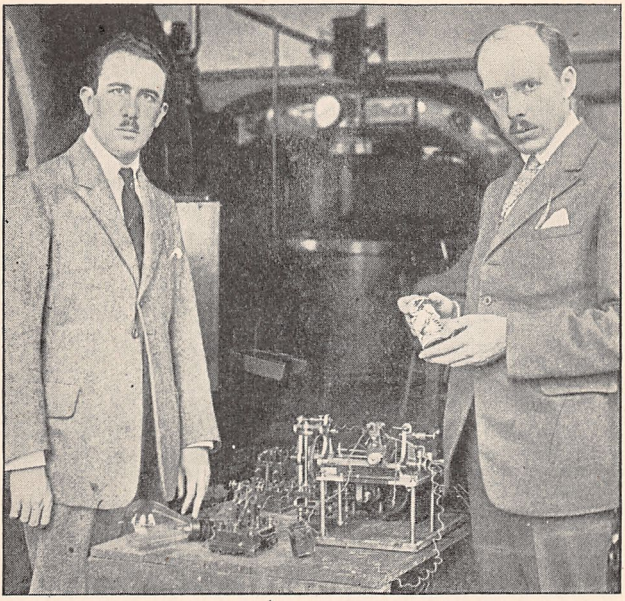
senting it are elevated or are separated by a non-conducting medium. A stylus passes over the surface of the cylinder, as the latter revolves, and alternately makes and breaks an electric circuit, as the point comes in contact with the conducting lines or dots or the intervening non-conductive surfaces, respectively.

At the receiving end, the place of the metal cylinder is taken by a cylinder with surface so chemically prepared that when the stylus that traverses it spirally conveys a current the surface will be discolored, remaining unaffected when no current is passing. By thus making a spiral series of dots or dashes the corresponding spiral of dots or dashes of the original picture may be reproduced; and when a chemically prepared paper covering the cylinder is cut lengthwise and spread out flat, it presents a reproduction of the original picture.

In a new apparatus developed by M. Belin, of Paris, the two phonograph cylinders, properly synchronized, are used as in the apparatus just described, but the place of the stylus is taken by a beam of light, which passes more or less readily through translucent picture (comparable to a photographic negative) wound about the glass cylinder. When the light passes more readily (representing high lights of the picture, the selenium cell is more energetically affected, and thus transmits electricity more readily; the variations in intensity thus modifying the current, and in effect modulating the radio waves that go out from the transmitting apparatus.

At the receiving end, the modulations result in varying the position of a translucent shield, which is graded in density of coloration from opacity at one end to complete transparence at the other, in such a way that a beam of light, passing through the shield and striking the revolving cylinder holding the photographic paper, is graduated in intensity and so affects the sensitized paper curiously, building up ultimately a spiral that represents the original picture just as in the other case.

By either method it is possible to transmit not merely ordinary pictures but any kind of line drawing, including written documents. An autograph letter, with signature, could be thus transmitted, provided the sending and re-



APPARATUS FOR TRANSMITTING PICTURES BY RADIO

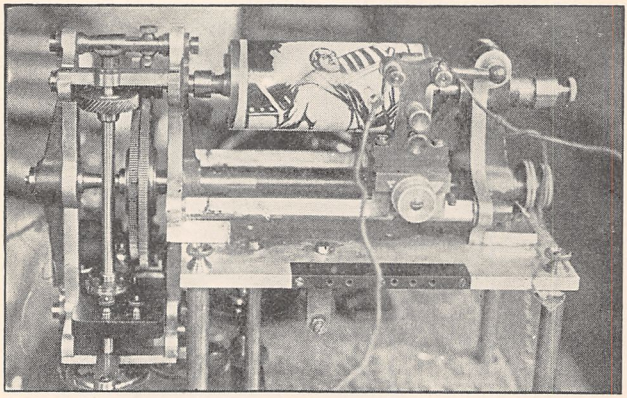
The particular apparatus here shown is the invention of two Frenchmen, Messrs. Gaston Toanneau and Marcel Touly, who appear in the picture.

ceiving apparatuses were properly synchronized; and it would thus become possible to authenticate a document, or to detect a forgery, with the aid of radio.

The experiment of sending a signature by radio across the ocean was made in April, 1921. The signatures of M. Briand and of General Pershing (if memory serves

me) were sent from Paris, and faithfully reproduced in New York a few minutes later.

The possible utility of such a method in the sending of secret messages is obvious. When an autographed document or picture is in question, whatever the wave length used in transmission, no receiving mechanism but one specially synchronized with the sending mechanism could



A "CLOSE-UP" OF THE APPARATUS FOR TRANSMITTING PICTURES BY RADIO

The picture is shown on a cylinder, like that of a phonograph. The stylus that conveys the electric current traverses the cylinder spirally, and the picture is built up at the receiving end on a corresponding apparatus.

interpret the message. The slightest failure in synchronizing would result in the production of an altogether meaningless muddle of lines or shadows.

It does not appear that the method of thus transmitting pictures by radio has hitherto reached a stage of development making available its general use on a commercial scale. But that may be expected to follow in the not distant future.

Meantime reference should be made to a quite different

manner of transmitting pictures by radio, which was utilized experimentally by a Los Angeles, California, newspaper in receiving a picture of the celebrated fiasco known as the Dempsey-Carpentier championship boxing contest held in Jersey City on July 2, 1921. The system here used was ingenious, consisting of a sequence of numbers referring to a prearranged diagram checked into a network so that each number would refer to a particular part of the diagram (as one might refer to a particular location on a chess-board); but no new scientific principle was involved, and the method does not call for further consideration in the present connection.

### PROF. KORN'S NEWEST METHOD

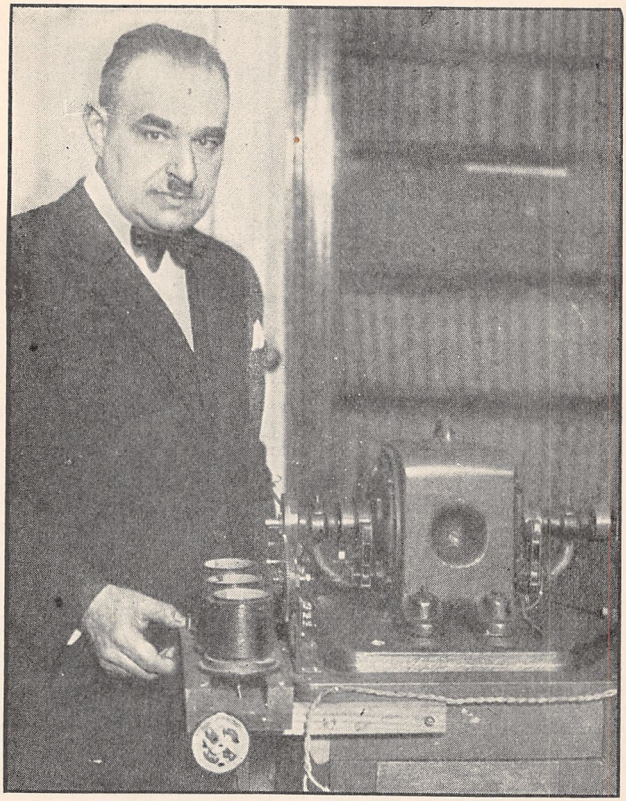
It is desirable, however, to go somewhat into detail in referring to a singularly ingenious method which represents the newest achievement in the way of sending pictures by radio.

If you were to see some one operating what appears to be an ordinary typewriter, and were to observe that the machine was producing a picture instead of a letter, you would doubtless be astonished. Astonishment would not be lessened when you were assured that the picture thus transcribed by the machine reproduces a photograph that had been taken within the half hour over in Europe. The explanation that the picture had come across the ocean in the form of a radio code would not offer much enlightenment.

Yet that phrase describes, after a fashion, the new method of sending pictures by radio that has been developed by Dr. Arthur Korn, of Berlin, with whose earlier work in this field we are already familiar. The machine that interprets the code is an ordinary typewriter, merely modified so that it types dots of various sizes instead of letters. The operator who receives the code has nothing

to do but strike in sequence the keys representing the groups of letters that have come by radio.

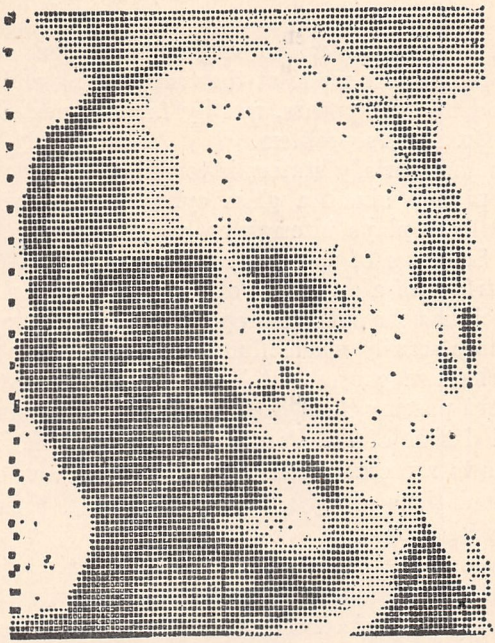
The picture thus typed out is made up of dots of dif-



PROF. ALFRED KORN'S APPARATUS FOR SENDING PICTURES BY RADIO

Professor Korn was an early experimenter, who successfully sent pictures a good many years ago by radio. His newest apparatus introduces the principle of sending a radio code, which is interpreted by a typesetter which types dots of various sizes, similar to the dots of a half tone picture, instead of letters.

ferent sizes, much like the ordinary half-tone printed in a newspaper or magazine. The dark portions of the picture are made up of larger dots; the light portions, of



Courtesy of "The World," N. Y.

A PICTURE SENT BY RADIO CODE

This shows a picture reproduced by Professor Korn's method in which the picture is built up by typing dots of different sizes. An ingeniously devised apparatus makes the code by letting successive letters of the alphabet represent different shades, as light is transmitted through a translucent negative upon a selenium cell, modifying the electric current.

smaller dots; and the intermediate shades of dots variously graded in size. When this is understood it is easy enough to see how the typewriter builds up the picture; and we begin to get an inkling of what the code

is like. The letter A, for example, of the keyboard may be represented by a fine dot, letting white paper show to make a high light; and the letter P, toward the other end of the alphabet, by a coarse dot, building up a deep shadow.

It remains, however, to explain how the code of grouped letters was made at the transmitting end of the line. And this, it appears, was by far the most difficult part of Dr. Korn's problem.

The method, briefly stated, is to roll a negative of the original picture about a glass cylinder, upon which a beam of light plays intermittently as the cylinder revolves. Shadows of varying intensity are thus thrown on the surface of a cell made of the strange metal selenium, which has the curious property of transmitting electricity more readily when illuminated. A highly ingenious mechanism causes a telegraphic key actuated by the current passing through the selenium to produce the dots and dashes of the Continental Morse code in such groups as to represent a different letter for each of seventeen gradations of light, so that the letters from A to P are represented.

The message sent by radio consists only of these groups of letters, and, of course, the typewriter that is to reproduce the picture is constructed with the same correspondence between letters and dots.

The transmitting machine works automatically, sending its groups of letters in sequence determined by lights and shadows of the picture; and at the receiving end an automatic recorder may take the message, reproducing the groups of letters in the same sequence. Then a typist, who knows nothing whatever about radio, may reproduce the picture by merely striking the keys of the typewriter in the sequence called for by the copy.

Thus the mystery of sending a photograph by radio across the ocean disappears—but not the wonder of it.

Even when we understand how the thing is done, it still remains a scientific miracle.

In general it may be said that the only part of the subject matter of the present chapter that is likely to have great concern for the amateur in the near future is that of the transmission of written communications. When the method above described, through which written documents may actually be reproduced, is sufficiently perfected to become available for the amateur, we shall have an entirely new aspect of the problem of personal intercommunication opened up. It will no longer be of consequence that many users of radio-receiving telephones may be "listening in." Secret messages may be sent by radiotelegraphic signals; and it is probable that by refined processes of tuning it will be feasible to operate many such instruments in the same territory simultaneously. The main difficulty encountered, it would appear, would be the interference of radio waves intended to convey quite different messages. Perhaps the mechanism can be so adjusted, however, that only waves of a certain intensity so well as of a certain length will affect the receiving mechanism, permitting a double safeguard. These are matters of detail, however, that must await the developments of the future.

## CHAPTER XIII

## THE ADVANCED AMATEUR AND HIS PROBLEMS

THERE exists in this country a very remarkable group of young men whose absorbing avocation is the practical and experimental investigation of the phenomena of radio.

Many of these young men are not yet out of their 'teens; few of them are much beyond thirty; but most of them have been pursuing the radio game, and are still pursuing it, with the ardor of neophytes although they have long since ceased to be novices. In the fullest American usage of the word, they are amateurs, in that radio has for them no commercial aspects; but they are amateurs also in the original French sense of the word, in that they are both lovers of the craft and accomplished masters of its every theoretical and practical detail.

There is no similar group of young men of corresponding size in any other country. It was the American boy, preeminently, whose imagination was aroused by the reports of the pioneer workers in radio, and who exercised his "Yankee ingenuity" in the endeavor to duplicate their achievements. The older members of the present group of master-amateurs began to play at the radio game not long after the Fleming valve was invented, say about the year 1907; or perhaps two or three years later, when DeForest had made available the magical audion, with its fascinating potentialities as yet only partly revealed.

These youngsters of ten or twelve or fifteen years, as they were then, had their youthful imagination fired by

the thought of being able to communicate through space, without tangible intermediary; and they set to work, with the creative ingenuity that is also an attribute of youth, to provide themselves with telegraphic apparatus that might enable them to grip the elusive ether. Mostly without expert direction, they learned how to manipulate that apparatus.

What some of them had achieved while the radio art was still formative, has been revealed to us in the record of young Edwin H. Armstrong, of feed-back fame, whose momentous discovery, it will be recalled, had been worked out prior to January 31, 1913, when official record of it was made. There are not many records to match that of the Yonkers boy, of course; but there were hundreds of youths, from Maine to California, who had achieved a creditable knowledge of radio, as it was then understood, and a large measure of skill in the sending and receiving of radio telegraphic messages, at a time when for the general public "wireless" telegraphy was scarcely more than a name, and "wireless" telephony scarcely more than a dream of the visionary; and when the word "radio," in its present-day acceptance, had not been added to the vocabulary.

Then came the war, and with it a world-wide intensive governmental study of "wireless" phenomena, to meet the very practical war-time needs. The public at large heard very little about these efforts, of course. They were war-time secrets. But after the war it came to be known that many remarkable things had been done, and that great strides had been made in the practise of the new art, which suddenly came to be spoken of as "radio,"—and appropriately enough so characterized, inasmuch as the word "wireless" had always savored of the paradoxical when applied to a method the practise of which requires the use of wires as the most conspicuous feature of the mechanism of both transmitting and receiving stations.

Most of the young amateurs of pre-war experience saw

service in France and found that their skill could be turned to good account in Signal Corps work which had practical application in every department of army life. Then, too, there were thousands of other young men who received their first introduction to radio, and were aroused to recognition of its possibilities and more or less trained in its practise, in connection with their military experience.

So when the war was over the band of radio amateur enthusiasts had expanded to notable proportions, and of course each practitioner of the new art became, consciously or otherwise, a propagandist, whose example would be emulated by a moiety at least of the wide-awake boys of his neighborhood.

And now of a sudden it appeared that the radio art had attained a new stage of development, making its elementary practise at once more fascinating and less difficult. Radio telephony had been achieved. So here was a field that offered alluring possibilities for the novice. No longer was it necessary to serve a long apprentice at the telegraph key in order to learn the rudiments of the art. The spoken word could be made to take the place of the mysterious clickings representing dots and dashes.

In particular, one could become a listener with the aid of the simplest apparatus (relatively speaking), and without the slightest preliminary training. It was even possible, if one grasped a few elementary principles, to construct a radio telephone receiving apparatus, out of odds and ends from the junk heap, almost; supplemented by purchase of a fragment of a little "crystal" and a pair of ear-pieces.

Under such circumstances, who would not become a radio enthusiast? Overnight the battalion of amateurs became a regiment; next month, the regiment had become a division. Suddenly it seemed as if the entire population had joined the ranks. The name of the radio fan was legion. Not to be interested in radio was not to be in

touch with the most compelling popular enthusiasm of the generation.

### SECRETARY HOOVER'S CONFERENCE

Yet it was a curiously silent invasion and conquest; and in the very midst of the army of occupation, the

SECRETARY HERBERT E. HOOVER USING A RADIO-RECEIVER

The calling by Secretary Hoover of a conference on radio at Washington early in 1922 did much to arouse public interest and call attention to the extraordinary progress of the new art.

great general public was scarcely aware of the significance of the new movement until the newspapers announced a conference in a room of the Department of Commerce at Washington, on Monday, February 27, 1922; and in particular chronicled the opening address of Secretary Herbert Hoover, which presented in direct and business-

like manner and in simple and unequivocal phraseology a statement of facts that had for the average newspaper reader an element of unexpectedness bordering on the sensational.

Here are the opening paragraphs of Secretary Hoover's remarkable address:

"It is the purpose of this conference to enquire into the critical situation that has now arisen through the astonishing development of the wireless telephone; to advise the Department of Commerce as to the application of its present powers of regulation, and further to formulate such recommendations to Congress as to the legislation necessary. This is one of the few instances where the country is unanimous in its desire for more regulation.

"We have witnessed in the last four or five months one of the most astounding things that has come under my observation of American life. This Department estimates that to-day over 600,000 (one estimate being 1,000,000) of people possess wireless telephone receiving sets, whereas there were less than 50,000 such sets a year ago. We are indeed to-day upon the threshold of a new means of widespread communication of intelligence that has the most profound importance from the point of view of public education and public welfare. The comparative cheapness with which receiving stations can be installed, and the fact that the genius of the American boy is equal to construction of such stations within the limits of his own savings, bid fair to make the possession of receiving sets almost universal in the American home."

The average reader rubbed his eyes as he read those paragraphs. Six hundred thousand radio receiving telephones in American homes, most of them introduced within the past few months!

Six hundred thousand—perhaps even a million!

And the prediction made that this is only a beginning —that soon the possession of receiving sets will be "almost universal in the American home."

Then the average reader, having rubbed his eyes and verified the message, became instantly a potential radio fan, and promptly sought the nearest store where radio equipment might perhaps be purchased. Then he found that his newly developed want could not be supplied. Hundreds of other applicants were before him. The makers of radio apparatus were swamped; the dealers in such apparatus were out of stock, with orders booked far ahead.

It seemed as if every American had determined to make Secretary Hoover's prophecy a reality in the very hour of its pronouncement.

The newspapers, responsive as always to public sentiment, established regular radio departments, and even radio supplements. Radio chronicles even assumed front-page significance. At last radio had attained publicity.

With astonishment the new-made fan and the would-be fan discovered that a new institution known as a Broadcasting Station had come into existence without his knowledge, and established itself here and there at the centers of population in all parts of the country; and that the air was literally vibrant (if only you had the kind of ears to respond to the vibrations) with weather reports and news reports and concerts and lectures and what not that had been passing not merely over his head but through his body totally without his knowledge. It was this cobwebbing of the air with messages that had led to Secretary Hoover's conference. A marvelous, an incredible, thing had been happening; a new era in the history of human communication, of the propagation of ideas, had come into being. He, the average citizen, had known nothing about it. It was high time that he became aroused and got him a radio-receiving apparatus—else he might find himself the only man in the world who did not have one.

Such, stated in barest outline, is the history of one of the strangest and most spectacular popular movements of

our time—or of any time. With a celerity quite without precedent, the radio-receiving telephone has imitated Cæsar's classical example. It came, it saw, it conquered, and to-day the population of America is divided into two subject classes: possessors of radio-receiving telephones, and would-be possessors of such telephones. It will not be long, apparently, before the term "radio amateur" will be coextensive in its implication with the term "average citizen."

### THE NEW ARMY OF AMATEURS

But of course the great body of this new army of enthusiasts are not amateurs except in the restricted American usage of the word. Most of them, as a matter of course, will never become expert players of the radio game. Indeed, for most of them, radio will never be a game at all. The radio-receiving telephone will be for them an implement of practical utility, just as the ordinary telephone is an implement of practical utility. It will serve the function of a super-telephone, plus the function of a super-newspaper. It will be a means to an end, and that end the garnering of useful information and of pleasant experiences. The generality of users of radio telephone will not be thought of as radio enthusiasts any more than the generality of readers of newspapers now are thought of as newspapers enthusiasts. They will simply be average citizens utilizing a conventional method of receiving information and entertainment, no more distinguished thereby than by using an ordinary telephone or reading a newspaper or on occasion going to the theater.

The exceptional individual here and there—usually a boy or girl, rather than an adult—will become a genuine amateur in the more restricted use of the word. He or she will not be content to remain a mere listener, but will wish to become a radio transmitter as well; and not merely an adept with the radio telephone, but also with

the use of the radio telegraph; since the latter offers, for the present at any rate, so much wider a field of operation.

Meantime we have with us a group of 15,000 or perhaps 20,000 genuine amateurs of the original advance guard; they whose achievements were under discussion at the beginning of this chapter. It is their recent achievements and some of the problems confronting them that we have now to consider, in order that we may gain a more comprehensive view of the present-day radio situation.

### SPANNING THE ATLANTIC

The most spectacular feat that these dyed-in-the-wool amateurs have accomplished through collective effort, or at least one that has most appealed to the popular imagination, is the spanning of the Atlantic with short-wave radio telegraphic signals. This was done in December, 1921.

The signals (and one complete message) were sent from more than a score of American amateur stations, variously located, and received at a temporary station set up at Androssan, Scotland, by Mr. Paul F. Godley, of Montclair, New Jersey, who had been selected at the First National Convention of the American Radio Relay League for the precise task thus successfully accomplished.

The achievement was so important, and Mr. Godley has so vividly described his experience, that we shall do well to take excerpts from the account he published in *The Wireless Age* soon after returning triumphant from his mission.

Mr. Godley assures us that there are in America 20,000 radio amateurs whose interest in the transmission of small-wave radio signals over greater and greater distances "transcends all else." He tells us that the task assigned him by the American Relay League, of going to

England as their representative in order to demonstrate to a skeptical public that American amateur signals could be registered across the Atlantic, held for him "the romance of strange, fascinating, delightful adventure; a

SENATOR MARCONI AND HIS RADIO SET ABOARD HIS YACHT

The famous inventor, despite his relation to professional radio, is sometimes referred to as the foremost of amateurs.

vision of the spirit of youth, vital eagerness, far-darting imagination." And much of his enthusiasm is revealed in his account of the adventure, though for the most part we must be content here, owing to limitation of space, to restrict ourselves to citation of the parts of his narrative that tell of the practicalities rather than the romance of

the enterprise. Yet these practicalities are in themselves romantic, as we shall see.

"On November 1st, 1921," Mr. Godley relates, "a preliminary test, which all were invited to enter, began, and the entrants transmitted on schedule each night up to November 5 in an effort to cover the distance of 1,000 miles overland, failing of which they were to be disqualified for participation in the main event. All my equipment was set for action, the super-heterodyne receiver being fed by a three-foot loop antenna. And what interest there was: Seventy-eight star stations scattered through every radio district, worked to schedule with clock-like precision. Station 5ZA in Roswell, New Mexico, consistently pounded in night after night on a four ohm telegraph sounder by virtue of relays in the circuit. Those were the first thrills.

"Then came the night of November 14, with a farewell dinner; and with all arrangements completed I sailed for England. Twenty-five contestants had qualified—two more were added later. At noon the following day the 'Aquitania' slid down the North River and I was off."

The ocean voyage, with its "occasional snatches of 200-meter stuff"; the brief stop in London, where he "listened in on all the strange commercial calls up and down the European shores," and was distracted on settling down to 200-meters by "gobs and gobs of static and whole orchestras of harmonics";—these furnished interesting preliminary experiences, but the main adventure began at Androssan, Scotland, at an improvised station with headquarters in a tent pitched on a rather forlorn coast.

Mr. Godley thus describes the final preparations and the moment of his triumph:

"On Wednesday, December 7th, the 1300-foot stretch of line was completed, the wire being supported by 2x4 inch posts 12 feet high, and laid out to point directly

toward Chicago. The wire was grounded at the distant end through a non-inductive resistance (250 to 400 ohms) and at the home end through a variable inductance of the order of 0.1 MH in value. [This is the so-called Beverage wire. It is comparable to the "wave-length" antenna system used at the great commercial station Radio Central, at Riverhead, Long Island.]

"Within the tent the regenerative receiver and super-heterodyne receiver were set up together with all accessories which were found to be in first class condition.

"At 11.30 P.M. all outside work had been completed and equipment arranged inside, whereupon the apparatus was gone over and put into operation. First the radio-frequency amplifier used with the super-heterodyne receiver was started up and time signals heard, without antenna, from both FL, Eiffel Tower, Paris, and POZ, Nauen, Germany. Next, the tuning equipment, which formed the super-heterodyne, was gone over in connection with a short wire which had been thrown into a nearby tree, and all circuits were adjusted while working on the multitude of 600 meter signals which were coming through. VCE, Cape Race, was there, and most as strong as any of them, and I took this as a good omen. Finally, the Beverage wire was thrown in, preliminary adjustments made at both ends of the wire, and tuning started, the first signal recorded being a host of harmonics from the high power stations, although these were not as bothersome as was the case near London. Search for short-wave amateur signals began at 1 A.M.

"At exactly 35 minutes later the universe cracked wide open! In one magic moment Scotland's erstwhile gloomy shores became a haven of rest! Muscle soreness, soul sourness, fatigue and doubt vanished, and my unexpectedly difficult but insistent duty became a joy forever! Cold rains then were as liquid sunshine; boisterous cutting winds as balmy, heaven-sent breezes. Nothing in the whole sad world could possibly be wrong—nothing, for an American amateur signal was piling in on us and rising in strength until at 1.42 in a very positive manner, his 60-cycle synchronous spark spelled out a message to

some one that he would 'see him later' and plastered the call letters 1AAW where the whole world might read!

"On the night of December 9 the weather had again gone very wet, and the winds had grown considerably heavier. Atmospherics were also heavier than the night before, being of about the same order as on the night when 1AWW was heard. At 12.50 A.M. on the morning of the 10th, after listening for sparks, we switched for continuous wave reception and immediately picked up station 1BCG (Greenwich, Conn.) on 230 meters. We had some difficulty with him due to atmospherics and a very bothersome harmonic from the station at Clifden, Ireland, 150 miles away. Both these were nullified to a great extent by various adjustments of both the apparatus and the line wire.

"On the night of December 10th-11th, 18 different stations were logged, the secret code words being gotten from three of them, while dozens were heard but not logged, either due to our inability to make out their weak signals through static—because of the number of stations working at one time and the resultant jamming—or because of the failure of stations, working locally, to use their station calls when transmission was ended.

"The most remarkable feature was the strength of some of these signals. 1 BCG's signals could have been heard easily 400 feet from the tent. Although we started out to see how far away he could be heard, we gave up the idea because of the rain which was coming down, and because of the time which would have been taken. 1ARY and 2FD (later 2FP) almost equaled 1BCG as to strength, during one or two very short intervals. 1BDT, a spark station, although by no means as strong, almost equaled 1BCG in steadiness of signals during a long period. Two of the continuous wave stations were using power of less than 30 watts!"

The climax came on the morning of December 12, when after hearing signals from dozens of stations at the same time, the eager listener caught a worded message, assuring him "hearty congratulations" from the Green-

wich, Conn., station, 1BCG, signed with the names of its owners and operators, "Burghard, Inman, Grinan, Armstrong, Amy, Cronkhite."

That was the first message ever sent across the Atlantic with amateur radio.

No readable signals from American amateurs were heard during the remainder of the tests. Presently atmospheric conditions ceased to be propitious, and the coming of a cyclone made it necessary to dismantle the tent on the afternoon of the 16th.

On the 19th Mr. Godley was back in London, and found that great enthusiasm was being shown as a result of the tests. "Station 1BCG had been heard by five British amateurs, by a Dutch amateur in Amsterdam, and by an American ship operator in the harbor at Hamburg, Germany, and all the newspapers in Belgium, France and the British Isles were featuring the story."

Mr. Godley goes on to say that British amateurs had heard signals from Salem, Cambridge, and Marion, Massachusetts; from Hartford, Connecticut; from Brooklyn, New York, and Valley Stream, Long Island; and from unidentified stations. He gives the complete list of stations heard by him at Androssan, to the number of about thirty, mostly located along the Atlantic seaboard, but including such interior stations as Burlington, Vermont; Cleveland, Ohio; Pittsburg, Pennsylvania, and Indianapolis, Indiana.

Notwithstanding the fact that two of the more distant stations, Cleveland and Indianapolis, used spark-wave transmission, Mr. Godley has very pronounced opinions as to the superiority of continuous wave transmission, as will appear from his concluding words:

"In glancing over the above lists one is struck by the preponderance of the C.W. stations, and by the fact that the British heard C.W. stations only. That can mean only one thing, that C.W. is far superior, and I should like nothing better than to see all amateurs change over

to continuous wave at once. Spark methods are horribly out of date, and are so inefficient, comparatively, as to be ridiculous, were it not that many have invested good money in spark equipment. Station 1AFV, since the tests, has gotten three messages across to England (London) on 200 watts of C.W. Many stations of the Atlantic seaboard are reaching to the California coast with similar powers, while the west coast stations have been shoving signals into the Hawaiian Islands. The day is not far distant when amateurs the world over will be exchanging greetings in many languages, and by the same token, the day is almost here when the spark stations will be of interest as having to do with history only."

### THE SUCCESSFUL TRANSATLANTIC STATIONS

Many readers who are not advanced amateurs themselves will be interested in details as to the amateur transmitting stations that sent the signals that reached Mr. Godley in Scotland. An interesting analysis of the equipment of the major part of the successful stations has been made by Mr. Robert C. Higgy, Hartford, Conn., and published in the radio journal *Q S T*, from which a condensed table that will repay careful examination has been reproduced in an earlier chapter of this book (see p. 300).

It will be seen that the twenty different stations listed show a considerable degree of variation as to details of equipment, but are closely similar as to fundamentals. The various prominent types of antenna—T, inverted L, cage, and V—are represented. Antenna heights range from 30 to 100 feet; and the total antenna length from 80 to 170 feet. For the most part, a counterpoise was used, sometimes composed of several or many wires; the number not necessarily coinciding with the number of antenna wires. In half the cases only a single oscillating vacuum-tube was used for transmission; in the other cases the number ranges from two to four. Input volt-

ages range from 350 to 6,000; the output in watts from 32 to 808.5 (a notable discrepancy); and wave lengths from 200 to 375 meters (only two, however, being in excess of 235 meters).

It is unnecessary here to make further analysis, as the reader who is specially interested can make this for himself. Meantime the novice must be impressed with the accurately scientific character of the data presented. It is obvious that the men who achieved success in sending these signals across the ocean did not succeed by accident, but through painstaking effort and full knowledge based on both theoretical study and practical experience.

That, perhaps, is the most important lesson that the novice can gain from consideration of the spectacular achievement of this group of expert amateurs.

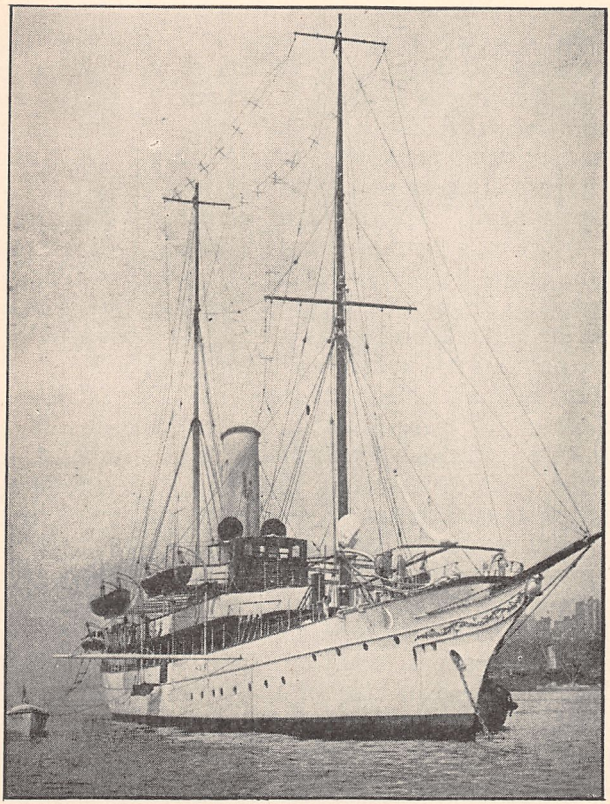
### SOME OPEN PROBLEMS

And what, it may be asked, are the important lessons that the experts themselves may draw from the demonstration? Or, viewed from a slightly different angle, what was the real significance of the spectacular test?

To attempt to answer those questions fully would involve a much more extended analysis of the test than can be permitted here. But at least one very prominent lesson taught by the aggregate experience is that radio, in the hands of the advanced amateur, has reached a stage of development at which it might be said to be in a measure standardized. The amateur novice who would become an expert can fairly judge, from study of the table here presented, on which comment has just been made, as to what are the limits within which he may advantageously experiment in the effort to develop a radio-transmitting equipment of high efficiency.

Answer might be made that as regards certain essentials, notably permissible wave lengths, the matter has been taken out of the amateur's hands and made subject

of official regulation. The field of wave lengths (provisionally) set aside exclusively for the amateur by Mr. Hoover's convention, as every person who is directly interested knows, was from 150 to 200 meters. Beyond



MARCONI'S FLOATING LABORATORY, THE *ELETTRA*

Senator Marconi is as enthusiastic an experimenter to-day as he was during the time of his pioneer work a quarter of a century ago. His marvelously equipped yacht affords him opportunity for uninterrupted observations during his voyagings.

200, and up to 275, the amateur shares the field with experimental stations. The amateur must confine his experiments, then, to wave lengths between 150 and 275 meters (representing respectively 2,000,000 oscillations and 1,090,909 oscillations per second). This puts a restriction on the inductance and capacity of his antenna system; but there is still opportunity for much diversity as to shape of antenna and number of wires and special arrangement, even if there is no great latitude permissible as to total length; or rather, to state the matter somewhat more accurately, even though there is rather sharp restriction on maximum length of wire.

Again as to the matter of oscillating transmission tubes (the only form of transmitter now to be suggested for use of the amateur), there is opportunity for diversity of usage; a single tube being used or three tubes or four in series, and different types of tubes (all, however, operating on the same principle), being available.

But these are after all details; and I repeat that the records of the trans-Atlantic senders show, in the general view, remarkable uniformity as to equipment and method. Mr. Godley has been quoted in enthusiastic support of continuous wave transmission, and in unequivocal condemnation of the now obsolescent spark or damp wave method. It goes without saying that the amateurs will be few indeed who in the immediate future will attempt an equipment for anything but continuous wave transmission. And, as already pointed out, the only available generator of these waves of such frequency as the amateur requires for the production of the short radio waves with which he is restricted, is the oscillating triode.

And as to such transmission, the transatlantic experiment constituted a demonstration of salient interest to both amateur and professional of the radio world. In particular is it noted that at least ten of the successful amateurs employed but a single tube for the generation

of the radio magnetic waves that were still sufficiently strong enough after crossing the ocean to make themselves felt by the amplifying triodes of Mr. Godley's receiving apparatus.

The significance of this is that experts have questioned the feasibility of securing power enough from a single tube to accomplish long-distance transmission.

So high an authority as Professor Morecroft assures us that "it is necessary at the present time to connect a number of the tubes in parallel, and adjust the several circuits so that they operate properly in order to accomplish satisfactory long-distance transmission. Limitation and output of one tube is due primarily," he adds, "to the inability of the tube to radiate the large amount of heat which it necessarily generated within the tube itself."

It should be stated, however, that Professor Morecroft, recognizes the probability that the limitations to which he referred would have but temporary significance. He goes on to say: "As improvement in design and construction occurs, under the extensive developments which are now being carried on, it may be expected that rating of tubes will continually increase, so that eventually this device may replace the present form of undamped wave generators. Oscillating tubes possess several advantages over all other high-frequency generators, principally: Ease of adjustment and reliability of operation, small space requirement, simplicity of construction, and relatively high efficiency."

The success attained by the amateur transatlantics with single tubes shows that Professor Morecroft's prophecy had been realized almost at the time of its expression. Doubtless there is still abundant opportunity for improvement, but the oscillating triode, as at present available for use of the amateur, is an instrument of marvelous efficiency. With its aid, American amateurs have demonstrated to the world that their restriction to the use of short wave-lengths puts no ultimate restriction

upon the geographical range of their radio activities. The results of the transatlantic test amply justify Mr. Godley's prophecy that: "The day is not far distant when amateurs the world over will be exchanging greetings in many languages."

### OTHER LONG DISTANCE RECORDS

Even now, by way of confirmation, we read of the consistent work of Mr. Dow (6VAC), of Hawaii, who "with a loose coupler, detector, and one stage of amplification, is hearing spark stations in the 5th, 6th, and 7th district and continuous wave circuits in these as well as in the 8th and 9th district"; among others, reporting NOF at Anacostia, British Columbia, a distance of 4,800 miles along the great circle.

We read also of the work of Major Lawrence Mott, 6XAD, at Catalina Island, California. With four 5-watt tubes, on a wave length of 220 meters, he reaches out across the continent to send signals to Westfield, Massachusetts; Brooklyn, N. Y.; to Washington, Philadelphia, Toronto; not to mention such relatively near places as Cleveland, Chicago, St. Paul, and a group of others of similar location. And all this, be it noted, over land—where the conditions of sending are notoriously inferior to the over-water route.

Major Mott's experiences are held by him to disprove for all time "the alleged theory that many stages of amplification are imperative for DX reception." He goes on to say that he has been working Lansing, Pennsylvania, Syracuse, N. Y., and Washington, D. C., with great regularity—"delivering messages to these stations on four 5-watt tubes."

In the opposite direction, also, Major Mott's messages are heard, for Mr. Dow, 6VAC, at Wailuku, Honolulu, writes to him: "You are very QSA [clearly audible] on one-step and all over the room on two."

All of which leads Major Mott to express himself as follows, in *Radio,* for April, 1922: "Where, then, enters the idiotic fallacy of many stages of amplification, with their attending expensive tubes, upkeep, numerous storage and B batteries, etc.?

"It is, to my mind, little short of the criminal to foist upon the rapidly-growing amateur class the entirely erroneous belief that vast power to send and much amplification to receive, are obligatory! Nothing could be further from the truth, and it is to this end that I herewith take pleasure in exposing the fallacy."

Cheering words, there, for the novice amateur, and words that have the ring of authority.

### LOOKING FORWARD

Not to multiply illustrations, it must be obvious that the field of short-wave radio, like that of long-wave, is destined to be the world at large. And, in particular, that successful long-range work is dependent rather upon skilful use of comparatively simple equipment than upon the multiplication of intricate accessories.

All this carries by implication the suggestion that the salient problem of the advanced amateur is, how to reach out into wider and wider territories. Just as an owner of an automobile, who at first is content to drive twenty-five miles wishes presently to advance his speed to thirty or forty miles or more, so the radio operator, enthusiastic at first over sending or receiving any messages at all, comes presently to wish for a wider and wider range of operation. Which is only to say that the radio operator is altogether human.

But the mere compassing of distances is by no means his sole ideal. The very fact of long-range work implies the sending out of ether waves of relatively great power (wide amplitude) on one hand and the relative sensitiveness of the receiving apparatus on the other. Both are

important; but in particular, from the standpoint of the amateur, is it important that the receiving mechanism should be made to have the utmost possible sensitiveness. An approach to perfection in this direction represents, doubtless, the great radio desideratum of the immediate future.

The significance of this comment will be more apparent when we recall that sensitiveness or relative efficiency of a radio apparatus implies not merely capacity to pick up exceedingly feeble messages, but also capacity to discriminate between messages of not very widely different wave-length. It implies, in other words, a receiving apparatus susceptible of very delicate tuning.

It is perhaps not too much to say that the entire future of amateur direct radio (in contradistinction to "directed radio" or "wired wireless") hinges on the solution of the problem of very accurate tuning of transmitting and receiving radio mechanisms.

Suppose, for example, that the accomplished amateur were able to tune both transmitting and receiving apparatus with such nicety that one would send and the other receive at a given time messages on waves of a length predetermined to a single meter;—waves, let us say, precisely 199 meters in length. Suppose that the receiving mechanism, as thus adjusted, would receive and translate 199-meter waves, but would ignore totally waves of 200-meter length or those of 198 meters?

Then, obviously, it would be possible for 125 different pairs of amateur stations to work in the same territory at the same time; each using its own particular wave-length (one for each meter within the prescribed limits of 150 and 275), and there might be almost indefinite interchange of confidences, without danger that any one would be overheard or interfered with.

If a transmitting apparatus of very low power was used in any given small community, so that the range of transmission would be restricted, it might very well come to

pass that the radio telephone would serve practically all the purposes of the ordinary telephone in a small community, with certain obvious additional advantages.

Conceivably there might be a local central station, to be addressed always on a certain wave length, to which appeal might be made at any given time as to what particular wave-lengths were at the moment available. Response to this being given, the prospective sender might call the desired receiver on the wave length set aside for that purpose (or the call might be sent from Central), after which the actual communication could be established by mutual adjustment of sending and receiving apparatuses at the designated wave length set aside for that particular conversation.

The conversation finished, the sender and receiver could in effect "ring off" to central by another adjustment of the dial.

All this may sound fantastic to-day; but something like it will probably be available in the near future. All that stands in the way of such a project now is the relative crudeness of the tuning applied to the average radio apparatus. It has been shown that it is possible to tune in such a way as to discriminate between waves differing by two per cent of the total,—that is to say, between waves of 200 meters and those of 202 meters. Even this, if applied to mechanisms used by the ordinary amateur, would suffice for an amount of personal intercommunication among radio operators that has hitherto been supposed, by the layman at any rate, to be quite impossible.

### MIDGET RECEIVING OUTFITS

The criticism might be made, however, and with a good measure of justice, that in such a scheme of local intercommunication by radio telephone as that just suggested, we are, after all, substituting the radio telephone for the

ordinary telephone, with perhaps no very striking advantages, considering that the telephone lines now run almost everywhere, even into the most remote districts of the country.

It could hardly be claimed, therefore, that the suggested extension of radio telephone, depending largely on

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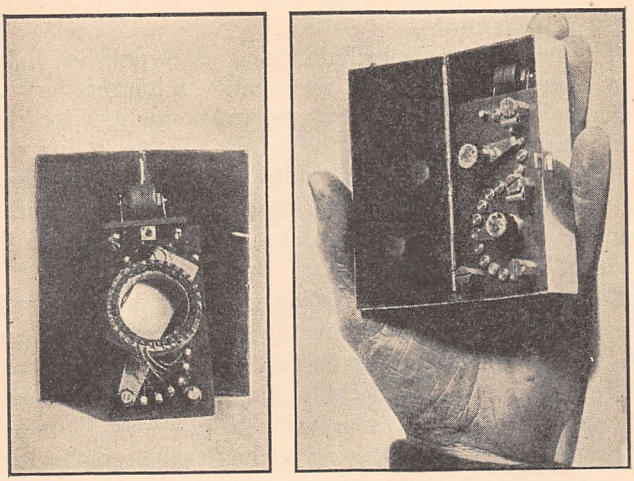
A RADIO-RECEIVING SET IN A SAFETY RAZOR BOX

The maker of this set is young Sydney Kasindorf, of the Bronx, New York City. The set contains a tuning coil, a variable condenser, and a crystal detector.

very accurate tuning, would be of notable advantage, unless there should be devolopment of method in yet another direction, through which it will become possible to do away with the cumbersome antenna system, and make the transmitting radiophone, and notably the radio-receiver, a portable apparatus. Until this is done, there can hardly be a question of rivalry between the two methods of telephoning; and when the readily portable radio apparatus is achieved, its effect will be to extend

the field of telephony, probably quite without question of curtailment of the wired telephone.

It was suggested on an earlier page that the time may come when radio outfits will be carried in the vest pocket, as we now carry watches; implying that the owner of the apparatus may thus keep himself informed as to the news not merely of the day and hour but of the instant, almost



DETAILS OF CONSTRUCTION OF A MINIATURE SET

as readily as he now keeps himself informed as to the hour and minute of the time.

We have now to enquire whether anything in present radio experience gives substantial support to such a prophecy.

At once there comes to mind the record of achievements of ingenious boys in various parts of the country who have vied with one another in the making of "midget" radio telephone receivers. Some of these—including a cubical one that is only an inch square at each side—have already been referred to.

The most recent report that chances to come to my attention, as I am writing, tells of the success of a New Jersey boy of nineteen, Alfred G. Rinehart, in making a radio receiving apparatus that fits as a ring around the little finger. The entire set, aside from the slender coil, covered with sealing wax, that encircles a finger, is said to measure 1 inch by 5/8 by 7/16 of an inch,—being therefore no larger than the rings that we frequently see worn as ornaments.

The measurements include the brightly polished bakelite panel on which are mounted a miniature crystal detector of the cat-whisker type, and a small switch control which is connected to the coil by nine taps, thus permitting as many different tuning adjustments by means of a movable brad which makes connection with one or another of nine tiny brass tacks, neatly arranged in the form of a semi-circle.

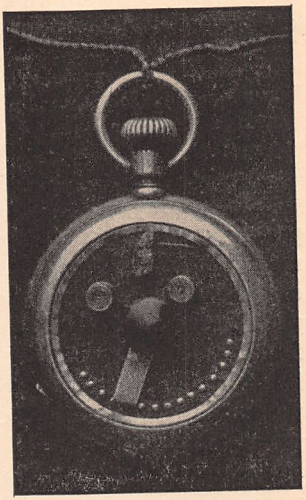
I am quoting the description given by Mr. Avery E. Lore, in the Springfield Sunday *Republican*, of March 26, 1922. Mr. Lore goes on to tell of young Rinehart's earlier achievements, notably his success in building a "Domino Midget" set, measuring only 1½ by 5/8 inches. He reports that the new ring set has a different hook-up from the other, and that the new arrangement appears to eliminate interference to a remarkable degree. Concerts or code messages can be received over the ring's tiny receiver, and undesired messages can be turned out more or less completely merely by moving the switch control on the ring.

It is reported that the material in this entirely practical little receiving outfit did not cost more than a dollar and a quarter.

All this is interesting; but we must not forget that the magic ring requires the aid of highly important accessories in order to perform its necromantic feat. The ring may be worn on the finger, to be sure; but it will be alto-

gether voiceless so long as it is not attached to certain wires that connect with an antenna system on one hand and a telephone receiver on the other.

Taken by itself, the magic ring is no more an interpreter of radio messages than, for example, a telephone receiver by itself is such an interpreter. One part of the apparatus is as essential as the other; and when both are attached to a cumbersome antenna system, including a ground system and an aerial perhaps fifty or a hundred feet in length, we obviously have a complete apparatus that is far from portable.



A RADIO-RECEIVING SET IN A WATCH CASE

It remains to be said, however, that young Rinehart has met this objection, and taken a step in the direction of the compact radio telephone outfit of our prophecy, by substituting on occasion an ordinary umbrella for the conventional aerial, meantime using a screw driver thrust into the earth for a ground.

With this outfit, it is reported, listeners at the young man's home in Elizabeth, New Jersey, heard messages sent out from the famous WJZ station in Newark "faintly, but loud enough to distinguish the tunes and hear the operator signing off."

The young inventor has been accustomed to use this umbrella-screw-driver antenna outfit with his earlier miniature sets, including the "Domino Midget" and the preceding one that was perhaps two inches square. The new ring set of course makes this earlier one seem cumbersome by comparison; and the ring is even more effi-

cient than the others. It has, for instance, nine taps, whereas the domino midget had only seven. The two-inch box worked up to 400-meter wave-lengths; the domino midget worked to 600; the little ring to 550. Of course the range cannot be very wide, as these miniature sets use crystal detectors. But what would you demand of an outfit that cost a dollar and a quarter and can be worn as a ring on your little finger, and operated with an ordinary umbrella as aerial?

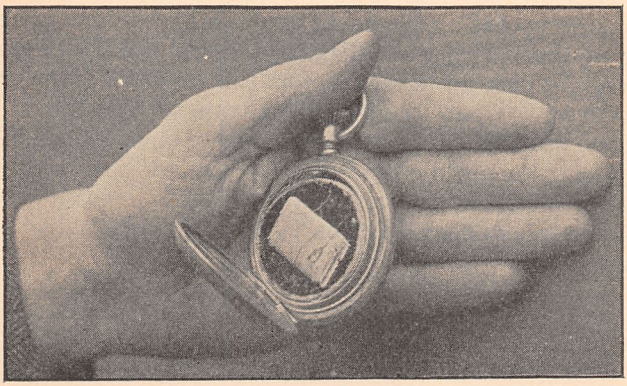
### PORTABLE SETS OF THE FUTURE

Here, then, is a practical receiving radio telephone outfit that is genuinely portable. Probably one of the tiny vacuum tubes used by Mr. Earl C. Hanson in his vactuphone hearing apparatus operated by a compact battery, might be substituted for the crystal, giving a detector of greater efficiency, without increasing the receiver beyond coat pocket dimensions. Presumably, also, a modification of General Squier's induction coil might be made to simulate a walking stick, as an effective substitute for the umbrella aerial. Dr. Miller's five-inch loop aerial will be recalled.

There would then remain only the relatively cumbersome ear-pieces to show that the carrier of such an outfit was differently equipped from his fellows. Even these might be kept out of sight in a pocket, a small tube with relatively inconspicuous tip fitting into the external orifices of the ears, after the manner of the physician's stethoscope, making the message audible.

Apparently there is no practical reason why the necessary induction coil and the crystal detector, or even a minimized vacuum tube, should not be made into a compact unit with a telephone receiver, the coil being wound about the receiver. The crystal set, at any rate, need not be much bulkier than a watch. The stethoscope-tube leading to the ear might be relatively inconspicuous, and

quite invisible when worn by a woman coifed in the prevailing fashion. The desideratum is the inconspicuous or invisible induction coil antenna. If this were spiraled within the lining of a coat sleeve it might, apparently, be as effective as General Squier's receiving induction coil already described; and possibly the coat-sleeve spiral



ANOTHER VIEW OF THE WATCH CASE RADIO RECEIVING SET

Sets like this may of course be classified as "freaks," but they have genuine interest and even importance, as preparing the way for practical, efficient sets to be carried in the vest pocket.

might be connected, directly or inductively, with a secondary coil worn as a belt; the two coils acting jointly as a loose-coupler, susceptible of adjustment by a movement of the arm, that might add greatly to the efficiency of the substitute-antenna apparatus.

For the matter of that, there would seem to be no reason why a coil of wire worn as a belt might not serve the purpose of a low-power loop aerial, associated only with a condenser carried in a pocket, and the telephone receiver, without the aid of such a sleeve-spiral induction coil as just suggested. It is true that such a belt-

loop-antenna (with or without the sleeve-spirals as accessory) would have only the smallest range of receiving power unless supported by one or more triode amplifiers; but there would appear to be no reason why these might not be compacted into something the size of an ordinary pocketbook. The "peanut" tube is already in evidence.

Here we have, in theory, a portable radio receiving apparatus that a man might carry in his trousers pocket or a woman in her handbag, that would enable the possessor to pick up messages from the air at all times and under divers conditions—while sitting in one's home or office, walking along the street, touring in an automobile, covering the golf links, cruising in a motor boat, or voyaging in a railway car. And that which is possible today may be depended upon to become an actuality tomorrow.

## CHAPTER XIV

## RADIO AS A PUBLIC UTILITY

NOT infrequently we hear the opinion expressed that the present extraordinary vogue of radio represents "a craze that can't possibly last." The holder of this opinion is usually a city man who has some friends with whom the receiving telephone is probably little more than a toy. There are many such, doubtless.

But the immediate future of the radio receiving telephone in the home does not rest primarily with the city dweller, who is within easy reach of numerous entertainments. It rests with the residents of the villages and with a farm population numbering thirty-odd millions.

Here are people who cannot step round the corner to an entertainment, nor gain the news from an evening paper.

But now the radiophone brings news and entertainment into their homes. An inkling of what this means may be gained by reading an account of the personal experience of a Kansas farm boy, named Hugh Stout, as related in the *Kansas Farmer* (Topeka). It is a matter-of-fact recital; yet even five years ago it would have seemed like a fantastic dream. The youth who is speaking lives away out in Kansas; but in his daily experiences he is a cosmopolite. Let him tell the story:

"We have been using a radio telephone receiving set for about a year and have been regularly receiving market reports, concerts, news items, conversations between operators, reports of stolen automobiles, descriptions of men hunted by the police, and a number of other things. On the evening of February 24 [1922], 23 heard

an organ recital from a church in Pittsburg, Penn., and a concert given by the *News*, of Detroit, Mich.

"The stations which we can hear best are Pittsburg, Detroit, Kansas City, Denver, and Madison, Wisconsin. We also hear occasionally from Oak and Wahoo, Neb.; Slater, Jefferson City, and St. Louis, Missouri; Chicago, Ill., Dallas and Childress, Tex.; and from our neighbors at Wichita, Great Bend, and Kiowa, Kansas. We get the correct time twice a day from Annapolis, Md.

"The set which we have is mounted on a wall board panel which is fastened to a wooden box containing a type 'B' battery for the audion tubes. The tuning portion of the apparatus consists of a three-coil mounting and two sets of coils and two variable condensers. One set of these coils is for the radio telephone and all stations using a wave length ranging between 180 and 450 meters. Two of the coils have 35 turns of wire while the third one has 25 turns. The other set of coils is for receiving messages from arc stations using a wave of from 10,000 to 20,000 meters in length.

"For a detector we have a Cunningham detector tube. The control for this detector consists of a rheostat, a type 'B' battery switch, and a fixed grid condenser. We use a Radiotron amplifier tube with a transformer and socket and a rheostat to control the current to the filament in the tube. We use two sets of 3,000 ohm receivers.

"The aerial is made of three wires about 125 feet long and 25 feet high. We have found that by using the telephone line in place of the aerial and the aerial in place of the ground, we get better results and have less interference from static electricity. This will not always work on all stations as it changes the wave length of the receiving set.

"A set like the one we describe will receive messages from the radiophone broadcasting stations and from spark wireless telegraph stations. It would cost a little more than $60 with a 6-volt storage and a 60-volt dry cell battery. We use a number of flashlight batteries connected together in series.

"We did not make up any of the units of this set which we use because we think that factory made instruments

are more satisfactory, since they have been made by experts and have been tested before being sent out. The units which we now have we mounted on the panels ourselves, but we had some help in hooking them up properly.

"We believe that farmers need radio sets more than city folks need them. We spend our evenings at home listening in on our radio set. We do not feel the need of going to other places for our entertainment when we can have such high class recreation right in our own home every evening.

"The other evening we had some guests here at the farm and all of us listened to a splendid concert by a symphony orchestra in Chicago. It cost us nothing to hear it and the music was very good. At 8.15 I changed the coils of my set for those adapted to the greater length waves and tuned up for a message from Annapolis which sends out the time every evening. For five minutes before the hour, the Annapolis operator dispatched a continuous signal that sounded like a mechanical hum, each variation marking the lapse of a second. At exactly the hour the sound stopped for an instant and the listeners set their watches to Government time sent through the air to a distance of more than 1,000 miles."

Here, then, we have a picture of the radio receiving telephone in the rural home. Let us turn now to another aspect of the picture.

### SPEECHES FOR THE FOLKS BACK HOME

It was inevitable that the representatives of the people in Washington should quickly recognize the new possibilities that radio afforded of keeping directly in touch with their constituents. It chanced that the first to take advantage of the opportunity was Senator Harry S. New, of Indiana, who on March 30, 1922, stood or sat in the Senate office building in Washington and delivered a political address to his constituents six hundred miles away. A correspondent of the N. Y. *Times* thus describes the novel incident:

"Mr. New had a large number of Republicans in his office to hear him deliver his long-distance radio appeal, including Chairman Adams of the Republican National Committee and a dozen Senators and their wives. President Harding and several friends listened to the Senator over the White House radio system.

"The Senator had prepared his speech and started to deliver it in a prosaic and matter of fact way, as a man would in talking over the 'phone. But the thing soon became so real that he grew emotional and departed at times from his written speech.

"The speech was delivered chiefly to a meeting of women voters in Indianapolis, but thousands of other 'phones picked up the message.

"Since Congress will not get away until the middle of August, indications are that many office-seekers will use the air route to reach the voters. Miss Alice Robertson, the only woman member, will speak to her constituents in Oklahoma to-morrow night.

"Senator New's successful venture into radio campaigning caused a lot of gossip and speculation in political circles. Some political experts expressed the optimistic opinion that campaigning by radio, soon might leave the field of novelty and become a practical every-day proposition during political fights. They admitted that any one who had suggested such a thing even as recently as the campaign of 1920 would have been ridiculed, but at the conclusion of to-night's performance they predicted that the radio telephone facilities in many sections of the nation would be tested to their capacity when the election campaigns were reached next Fall.

"The development of the radio telephone has reached a point where addresses not only can be delivered to crowds in a great auditorium, but to hundreds of homes in almost every Congressional district of the country where receiving sets have been installed during the last six months. In some districts the sets in homes are numbered by the thousands.

"Local receiving stations reported to-night that they had picked up Senator New's speech without trouble and that every word could be heard. Similar reports came

from radio users more than 800 miles away. There wasn't a shred of doubt in the minds of radio enthusiasts that plans for radio campaigning were practical and that they would be distinctly the vogue before many weeks had gone by."

THE ONLY WOMAN MEMBER OF CONGRESS APPEALS TO VOTERS BY RADIO

Representative Alice Robertson, of Oklahoma, seated in her office in Washington, is addressing thousands of her constituents in Oklahoma. This was among the first of political speeches broadcasted by radio.

The matter had indeed assumed such significance from the standpoint of some at least of our representatives, that, even before Senator New's speech was made, Representative D. M. Brennan, of Detroit, Michigan, had introduced in the house a bill calling for the installation of broadcasting apparatus in Congress, declaring that "a permanent and beneficial result of this application of the radio will be the reawakening of public interest in the doings of Congress."

THE GENERAL SIGNIFICANCE OF BROADCASTING

The political possibilities of the use of the radio telephone represent, however, but a very small part of the scope of the new art as a practical public utility. In a recent article in *Leslie's Weekly,* Mr. Arthur Ruhl gives a graphic account of his own feelings after hearing his first radio concert, and goes on to present an interesting view of the amazing recent growth of interest in radio, and in particular the broadcasting phases of it that are at the moment claiming our attention.

Under a picture that shows a family group of three generations "listening in" we find a caption which summarizes the situation thus: "For a time interest in the wireless telephone was confined to a few sapient scientists who talked a jargon that failed to arouse any enthusiasm with the ordinary mortal. Then the small boy suddenly discovered that he could have a world of fun with a 'radio' telephone. Presently the small boy's elders became interested. Men, women and children caught the wireless fever, and as a result to-day there are in this country over 600,000 persons who own apparatuses with which to receive wireless messages."

Mr. Ruhl gives us illustrations of the reactions of some of the listeners to the messages that come to them out of the air. For example:

"An Englishman, employee of a power company buried somewhere in the Canadian snows, wrote the other day to the American company which 'broadcasts' a daily wireless telephone service—news, music, sermons, crop and weather reports and so on—from Newark, N. J.:

" 'I stepped outside the shack for a while, while they were listening to you inside. It was a cold, clear, bright night, stars hanging like jewels from the sky, five feet of snow, 42 below zero, not a sound but the trees snapping in the frost, and yet, if everybody only knew it, the air was full of sweet music.

" 'I remember the time when to be out here was to be out of the world—isolation complete. Not a soul to hear or see for months on end. Six months of snow and ice, fighting back a frozen death with an ax and stove wood, in a seemingly never-ending battle.

" 'But the long nights are long no longer—KDKA (call name for one of the transmitting stations) and WJZ are right here in the shack shortly after sundown, and you come in so plain that the dog used to bark at you, even though I had the headphones clamped tight on my head. He does not bark any more. He knows you the same as I do—just pricks up his ears at first, then sits blinking at the bulbs and listens. . . .'

"In the offices of the 'broadcasting' companies," Mr. Ruhl continues, "you will find hundreds of letters of this sort—not so eloquently expressed, perhaps, but each telling in its way, how magic came out of the air to people listening hundreds of miles away. There are letters full of technical jargon which the writers themselves wouldn't have understood a year ago, probably, and which the greater part of the intelligent public wouldn't understand to-day—the use of 'broadcast' as a verb is a matter of recent months. There are letters from invalids who listened to concerts or sermons from their beds; from farmers or farmers' wives, grateful for news of market prices; from ships' officers at sea; and from the American small boy, whose interest in the wireless telephone is so important an element in the development both of the telephone and of the small boy himself, that the Government, the other day, in the person of Mr. Hoover, announced its intention to protect it.

"The present popularity of the wireless telephone began with the establishment of powerful 'broadcasting' stations which send out a regular daily program of news, special talks of various sorts, sermons and music. The waves are flung out into space, they spread in concentric circles just as the waves spread on a quiet pond when a stone is flung into the water, and all the individual has to do is to hang up his aerial wire, attach it to his receiver and anything he can pick up is his. No thought

or bother, but something going on every hour on the hour, and in the evenings a regular concert.

"About one-tenth of the population of the United States can be served by WJZ (Newark, N. J.)—by its every-day, normal broadcasting that is to say, and not considering the chance conditions that permit messages to be picked up somewhere in the Pacific. Among the other well-known stations are KDKA at East Pittsburg; WBZ at Springfield, Mass.; KYW at Chicago (all these Westinghouse); 1XE (Amrad) near Boston; WDY (Radio Corporation), Roselle Park, N. J.; 6XG (Atlantic Pacific) at San Francisco; 6XG (Meyberg) at San Francisco, and 6XAK (Meyberg) at Los Angeles.

"There are stations at various colleges. The physics department of the University of Wisconsin broadcasts over a radius of sixty miles in broad daylight and further at night. (Radio waves carry better at night than in the daytime and better in winter than in summer.) The University sends out weather reports, market and other news of special interest to farmers, concerts and so on, and it has issued mimeograph forms so that the receiver can jot down the information picked up with a minimum use of time.

"A typical week's program broadcasted from WJZ recently included a Sunday sermon, stories for children, talks on such varied subjects as play-writing and hygiene of the mouth, 'How to make a House into a Home,' and writing scenarios for the movies, and all sorts of vocal and orchestral music. Naturally most of this station's broadcasting is picked up in the New York neighborhood by people with inexpensive home receiving sets. When the distance is greater than fifty miles, a set with what is called a 'vacuum tube detector' instead of the cheaper 'crystal detector' is generally necessary, and such a set may cost anywhere from $50 up. As the distance increases there must be amplifying apparatus and other refinements. Roughly speaking, and considering comparatively short distances, it is said that the cost of wireless receiving telephone apparatus is about $1 for every mile of distance from the transmitter."

AN EXPERT'S OPINION ABOUT BROADCASTING

It will be of interest to supplement this chronicle of a casual listener with the carefully thought-out expression of opinion of an expert who has to do with the creative side of broadcasting. The expert in question is Mr. M. P. Rice, Manager of the General Electric Company's Broadcasting Station. In an article published in the New York *Globe's* radio supplement, Mr. Rice thus calls attention to certain conditions, and makes interesting prophecies as to the future influence of the new public utility:

"Radio telegraphy is more than twenty years old, but radio telephony, in its present form, is a very recent product of inventive genius.

"Only a year ago there were hardly fifty thousand radio receiving sets in the United States. According to a recent estimate there are now more than half a million, and there are sending stations of sufficient power to cover the entire area, under favorable conditions. The aggregate number of those who 'listen in' to the evening programs of the broadcasting stations probably approaches a million, and the audience reached by a single station may be ten thousand or more. When all the people have access to receiving outfits, a speaker at a powerful broadcasting station might address the entire population of the United States at one time.

"The radiophone is therefore a new publicity agent which literally has everybody 'by the ears.' It immediately takes its place with the telegraph, telephone, post office, press, pulpit, school, and theater as a means of reaching the public, and its possibilities are obviously so great that it cannot be regarded as a plaything or a passing fad.

"What is likely to be its field of application in the immediate future? In suggesting an answer to this question we do not need to draw heavily on our imagination. Radio has already spurned the limited creations of imag-

inative writers and has again proved that fact is stranger than fiction.

"The telephone has not supplanted the telegraph, and radio is not likely to supplant either. It is already in general use for transoceanic communication, and this application will be extended, but radio will not under present conditions supersede the telegraph or telephone for obvious reasons. Broadcasting the morning order for groceries or a chat with an intimate friend might be more entertaining than practical.

"The great publicity field for radio is the broadcasting of information or entertainment designed to reach large numbers. If the matter is of universal interest and importance it would be radiated from a few suitably located stations of great power. Matter of more local interest would be broadcasted from less powerful stations, which would be installed at suitable intervals throughout the land.

"National news would be broadcasted from the few powerful stations, and local news from the numerous local stations. The President of the United States might address the entire population from a high powered central station; the governor of New York might address the people of the State through a local station. The message in either case would reach instantly localities not reached by telephone, telegraph, postoffice, or newspaper.

"The distribution of music and other forms of entertainment, and the broadcasting of educational and religious programs will undoubtedly develop along similar lines.

"Radio broadcasting, which is now being done largely by manufacturers as an experimental accessory to the development of the art, will undoubtedly be undertaken as a public service, the details of which will have to be worked out.

"Ten thousand individuals could probably not be found who would be willing to read consecutively every page of the same newspaper or magazine, and it is not reasonable to suppose that the radio audience will all want the same program at the same time. Therefore, an assortment of wave-lengths will be provided—one for market

and weather reports, one for financial reports, and others for local news, for advertising, for concert music, for dancing, for educational programs, for church services, and for theatrical productions.

"Radio will exert a powerful influence on the press, the pulpit, the schools, and the theatre, but it will not supplant them. Public taste will be educated, and it will be more critical. It will demand higher standards. There will be beneficial evolution of press, pulpit, school, and theatre, in which the inferior and the mediocre will be eliminated.

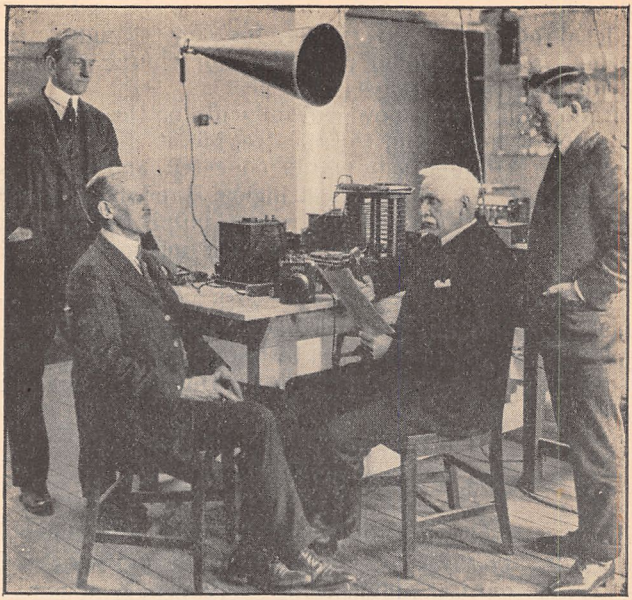
"Radio broadcasting carries with it responsibility. It is to be hoped and expected that the power to say something loud enough to be heard by thousands will give rise to a desire to say something worth while, and to say it well."

### A COLLEGE COURSE BY RADIO

There is wholesome admonition in Mr. Rice's concluding words. To say something worth while and say it well will be the natural ambition of every person of normal sense of responsibility when called upon to address an audience running into the thousands or tens of thousands. Already there is evidence that broadcasting has present-day possibilities of educational influences that are more than casual. In the *Christian Science Monitor,* of March 27, 1922, we find an account of a new enterprise in which a prominent educational institution has taken the initiative in a movement that doubtless will be country-wide.

The institution in question is Tufts College; the novel "university course" to be inaugurated is thus described:

"Tufts College has announced that members of its faculty will give a course of 13 lectures by radiophone, on a wide range of topics, the course to be completed by June 1. The lectures will be given twice a week. This will be the first attempt anywhere, it is said, to use the wireless telephone for educational purposes. A unique



MEMBERS OF THE RADIO FACULTY OF TUFTS COLLEGE, MASSACHUSETTS

Tufts College was among the first institutions to institute a regular course of lectures by radio. The lectures were estimated to reach 35,000 persons, as far west as Wisconsin and as far south as Florida. Of the thirteen members of the "radio faculty," the ones shown here, left to right, are Dr. Arthur I. Andrews, who will speak on "Changes in Europe"; Prof. Edward H. Rockwell, who lectures on "The Story of the Bridge Builders"; Dean Gardner C. Anthony, whose subject is "The Story of Engineering"; and Professor Albert H. Gilmer, who deals with "The Modern Drama."

feature of the new method of teaching will be that anyone properly equipped with a receiving outfit can 'listen in' to any or all of the lectures, free of charge. The broadcasting apparatus of The American Radio & Research Corporation at Medford Hillside will send out the lectures, which will be available to more than 35,000 persons

within a circle extending as far west as Wisconsin and as far south as northern Florida.

"Dean Charles Ernest Fay, Wade professor of modern languages and dean of the graduate school, will give the opening address, to-day or early next week.

"He will describe the lectures to be given and tell of the aims of the course. As a lecturer on literary and geographical topics, Dean Fay is well known. He has been a pioneer of mountaineering in the Canadian Rockies and the Selkirks. Mt. Fay in the Selkirks was named after him.

"Dr. Harvey A. Wooster, Jackson professor of political science and head of the department of economics, will deliver the second lecture on 'The Story of Money.' Dean Gardner C. Anthony, of the engineering school, will talk on 'The Story of Engineering.'

"Other speakers and their subjects are: 'Changes in Europe,' by Dr. Arthur I. Andrews; 'Preparedness Among Animals,' by Dr. Alfred Church Lane; 'The Story of Archeology,' by Dr. William F. Wyatt; 'Athletics,' by Clarence P. Houston, assistant professor of physical education and a former football star at Tufts; 'The Story of the Bridge Builders,' by Prof. Edward H. Rockwell; 'The Conservation of Bird Life,' by Dr. Herbert V. Neal; 'College Music,' by Prof. Leo R. Lewis. The lecture by Professor Lewis will be illustrated by selections by members of the Tufts College Glee Club. Prof. Albert H. Gilmer will speak on 'The Modern Drama,' and Dean Lee Sullivan McCollester of the Crane Theological School on 'The Place of the Minister in Modern Society.' 'Story of Architecture' by Prof. Edward H. Wright.

"In the initial statement it is made clear that the lectures will be of a popular nature and not beyond the understanding of the thousands of young men and boys, between the ages of 15 and 25, who are especially interested in wireless. The lectures will not exceed 30 minutes in length and will be delivered in such a way that students can take notes if desired. Some of the lectures will be given in the afternoon in order that women, many of whom are taking an interest in the radio telephone, may listen.

"Those in charge of the new course at Tufts say that by the use of the sound amplifier it will be possible for many persons to hear the same lecture from one receiving apparatus. But the most notable advantage of the Tufts Wireless College plan seems to be personal relation between the professor and his students, a relation that is altogether lacking in correspondence courses. Under the present system it is impossible for any student to ask a question of the lecturer and receive a reply, but it is not beyond the range of possibility that the professors will set aside one or more lectures to the answering of questions that have been submitted by mail.

"In discussing the new method of teaching, a member of the Tufts faculty admitted that it was frankly an experiment. 'Whether we shall meet any demands on the part of the public by giving these lectures remains to be seen,' he said. A very large part of the radio broadcasting now is being done purely as a public service. Tufts College seeks to serve the public in every possible way and several members of the College faculty have volunteered to undertake this work without remuneration. The possibilities are manifold, and it is only a matter of a short time, in my opinion, when information of all kinds will be transmitted by radio."

### BROADCASTING RESTRICTIONS

It is scarcely necessary to present more evidence of the position that radio broadcasting has attained as a public utility in the first few months of its existence. Indeed, sufficient evidence was supplied by the circumstance, already related, that complications present and prospective, growing out of broadcasting, were chiefly responsible for the calling by Secretary Hoover of the National Conference that met in Washington in February, 1922.

At that conference, as most persons who have occasion to be interested have learned, certain recommendations were made as to the control of the public highway of the ether. It was recommended that different groups of

wave lengths be reserved for different types of radio transmission.

The allocation of waves, as decided on by a committee, and officially reported, is as follows:

"Transoceanic radio telephone experiments, non-exclusive, 6,000 to 5,000 meters; fixed service radio

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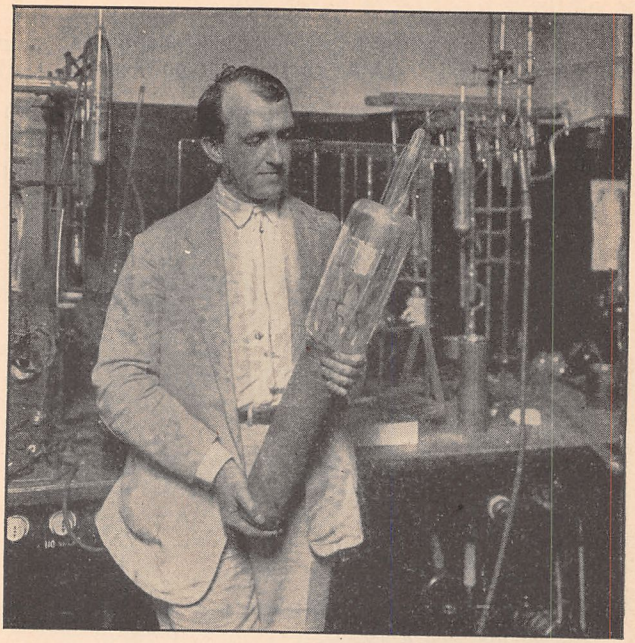
SENDING GOVERNMENT STATEMENTS BY RADIO FROM WASHINGTON

This is Mr. T. C. Gale, a man whose voice reaches thousands of listeners each evening. He is at work in the Post Office Department at Washington broadcasting official messages of general interest.

telephony, nonexclusive, 3,300 to 2,850; mobile service, nonexclusive, 2,650 to 2,500; government broadcasting, nonexclusive, 2,050 to 1,859; fixed stations, nonexclusive, 1,650 to 1,550; aircraft radio telephony and telegraphy, exclusive, 1,550 to 1,500; government and public broadcasting, 1,500 to 1,050; radio beacons, exclusive, 1,050 to 950; aircraft radio telephony and telegraphy, exclusive,

950 to 850; radio compass, exclusive, 850 to 750; government and public broadcasting 700 miles inland, 750 to 700; mobile radio telephony, nonexclusive, up to 650;



MR. W. G. HOUSKEEPER, WITH HIS 100-KILOWATT TRIODE

This is the largest power tube hitherto constructed. Such tubes will probably supplant all other types of generators at the commercial stations. A successful test of transatlantic sending with 20-kilowatt tubes was made at Radio Central, Long Island, October 15, 1922.

mobile telegraphy, exclusive, up to 525; aircraft radio telephony and telegraphy, exclusive, 525 to 500; private and toll broadcasting, exclusive, 435 to 310; restricted special amateur radio telegraphy, non-exclusive, 310; city and State public safety broadcasting, exclusive, 285

to 275; technical training schools, shared with amateurs, 275 to 200; amateur, exclusive 200 to 150; reserved below 150."

The amateur, in his capacity of listener, may be interested in any and all wave-lengths, although the extremely long ones do not fall within the range of his tuning apparatus. The transmitting amateur, except in unusual cases, must confine attention to wave-lengths between 150 and 275 meters in length. These short waves, as we have seen, call for rapid oscillation on the part of the transmitting apparatus, but these are precisely the oscillations that the transmitting apparatus of the amateur—the vacuum tube, namely—can deliver with unrivaled discrimination and efficiency. Having exclusive rights to fifty wave-lengths, and joint use along with the experiment stations of seventy-five additional wave-lengths, the amateur has abundant range for his activities, and may feel that Secretary Hoover's conference gave him adequate recognition.

It remains for the amateurs themselves to devise rules for the best utilization, for the common good, of the particular gap in the ether which is their allotted territory.

Meantime the private and toll "broadcasting" stations, with exclusive use of waves ranging from 310 to 435 meters, must by mutual arrangement divide up their ether-territory in such wise as to minimize or prevent interference in overlapping regions. Up to the time of the Washington Conference, most of them had been broadcasting on 360 meters; but as the range of influence of the individual station increases (already the General Electric Station at Schenectady has been heard across the Continent), it will become increasingly necessary to have different stations transmit on different wave lengths, so that the multitudes of listeners may select their programs, and not be subjected to an ethereal confusion of tongues.

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